
LABORATORY

OF THE AIR

PREPARED FOR THE MINISTRY OF SUPPLY
BY THE CENTRAL OFFICE OF INFORMATION

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LABORATORY OF THE AIR

An Account of the Royal Aircraft Establishment of the Ministry of Supply Farnborough

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Contents

Illustrations

Per Ardua ad Astra

The sage wrote in the Book of Proverbs

" There be three things which are too wonderful for me, yea, four which I know not :

The way of an eagle in the air ; the way of a serpent upon a rock ; the way of a ship in the midst of the sea ; and the way of a man with a maid."

The last of these has been the universal problem of mankind down the ages, and the third has concerned our island story through the centuries ; understanding of the first has been the purpose behind the endeavour of the Royal Aircraft Establishment during the last decade.

To the story of that endeavour these pages are dedicated.

ONE

A THREAD OF THOUGHT

IN the sunny days of the eighteen-nineties, when eyebrows were raised at Air Estimates running into four figures, the citizens of Farnborough and Aldershot were from time to time outraged by an extraordinary progress which rattled their windows and (they declared) shook their houses to the foundations. Their complaints were perhaps not without justification : they related to the activities of the formidable Colonel J. L. B. Templer, a relentless pioneer of mechanical progress on the ground and in the air, who made a practice of taking his wife shopping in a caravan hitched to a ten-ton traction-engine. When he was not urging people into conquest of the air, it was his pleasure to urge his traction-engine driver to thunder at speed through the last placid afternoons of the Victorian era.

In the perhaps even sunnier days of the eighteen-eighties, when the first Air Estimate was introduced at £600, Templer had acquired the proud title of Instructor in Ballooning ; but times were changing, and visitors who arrived by train, and were met by traction-engine at the London and South Western Railway Station, came to consult the Colonel as Superintendent of Her Majesty's Balloon Factory. Strange things were happening at Farnborough—almost incredible ascents into the air. They were a menace to timid horses, a delight to inquisitive boys, and an everlasting source of curiosity to young ladies. There was something more than eccentricity, however, about this fellow Templer. Not only the intolerably anti-social traction-engines (which were used for army transport) were being sent to South Africa ; airmen were going too, to fly balloons against the Boers. Discretion almost amounting to secrecy enveloped the matter ; no one could wring much information about it from the young apprentice Percy Crosson.

Nearly fifty years later, in the forties of this century—let us not pause to quote the figures of the current Air Estimate—the citizens of Farnborough and Aldershot, inured to noise, were startled (almost to the extent of going to ground, some declared) by a din which penetrated every nerve of the body. Neither inquisitive boys nor romantic young ladies would by now think of asking that same Percy Crosson for information, for they had long been drilled in the duties of " security." The one-time apprentice who had trembled before the inventive

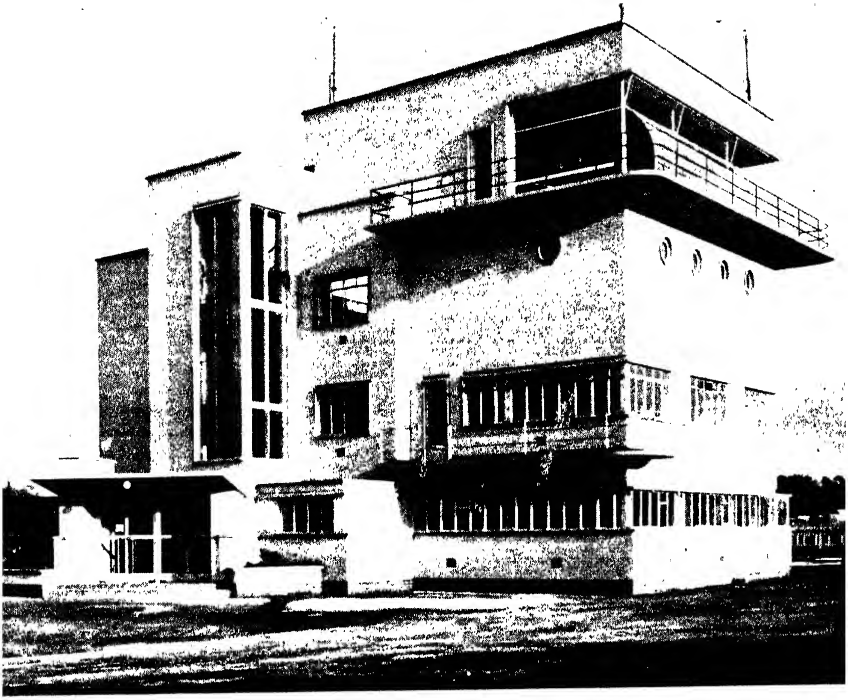
ferocities of Colonel Templer was now Shop Superintendent of the Royal Aircraft Establishment ; he had been working his staff day and night for three weeks in order to produce a copy, from put-together pieces, of the first of Hitler's secret weapons, the V.1. The thing was running captive upon a testing bed, shaking the very earth, causing pots to fall off shelves a hundred yards away, and justifiably outraging the feeling of the citizens of a considerable part of Hampshire.

Here, at that critical time of our history, with the cheap (they cost no more than a small car) and nasty weapons falling thick and fast upon the capital and the south of England, many of the acutest aeronautical brains in the country were assembled and focused upon the V.1 built by Crosson's men. They formed a significant force in the battle of wits which went on behind the outward clash of global warfare. They were well equipped for quick trial and study of the V.1 ; the organisation to which they belonged had as long ago as 1917 designed and built pilotless aircraft, and had in 1929 created a British long-range example—intended for use as a flying bomb, and called a Larynx—which flew distances of over a hundred miles above the deserts of Iraq before the idea was officially abandoned. Work on the V.1 was only an episode in seventy years' pursuit of scientific knowledge in the realm of aeronautics.

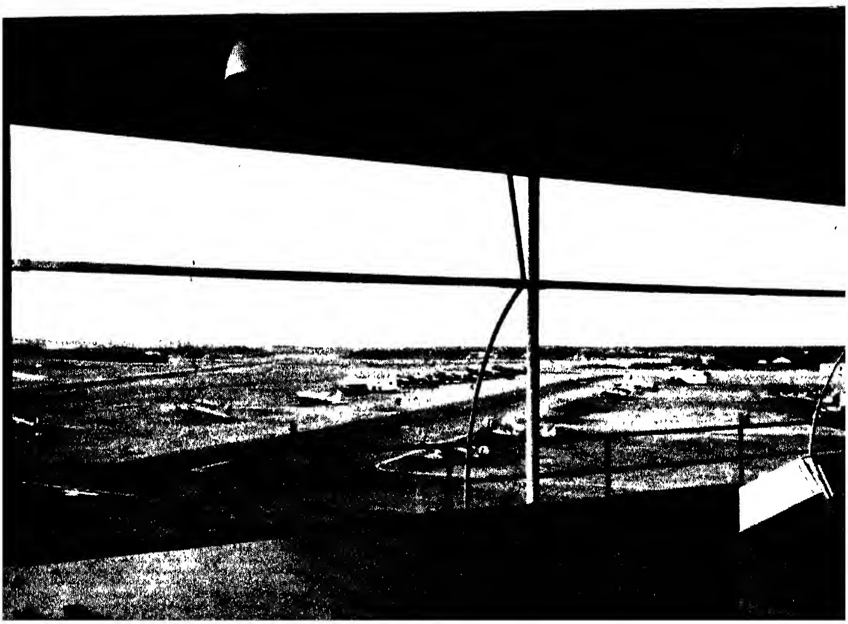
Aeronautics have become the most significant single force for good or evil in the hands of mankind. The Farnborough workers occupy a township of fantastic pattern—weird ranges of buildings and sheds which have mushroomed up through the years on one corner of Farnborough Common. Against those workers and throughout the war, in University cities, in remote research stations and secret mountain retreats, the aeronautical experts of the Third Reich carried on a ceaseless struggle. There can be no doubt that without this Farnborough community of buildings and brains, of aircraft and plant, of calculation and experiment, the end of the war might have been very different.

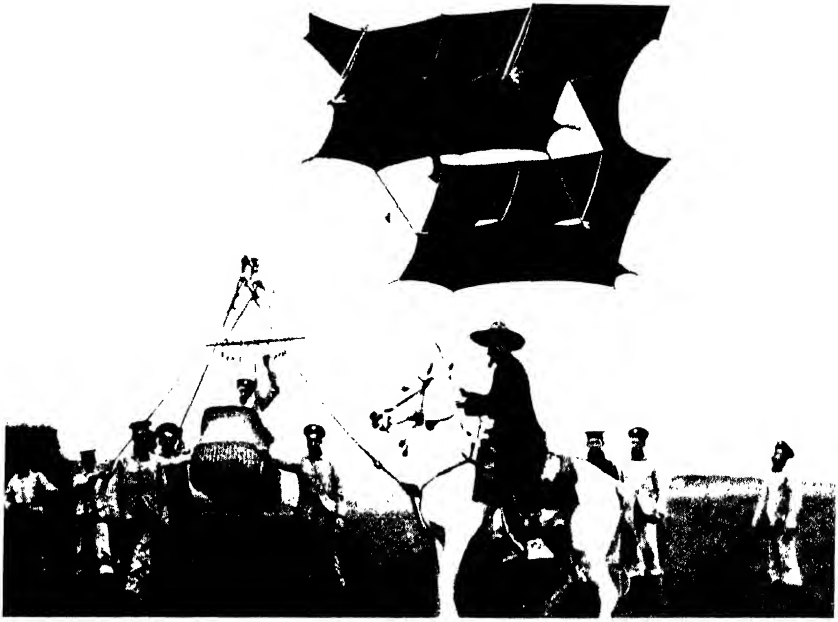
The rank and file of the Royal Air Force, with light-hearted awe, referred to the community collectively as " Boffins." It is difficult to find any other general term to describe the men and women of the Royal Aircraft Establishment, with their great diversity of talent and activity. The thread of their thought, inquiry, and experiment can be traced, in good and ill fortune, back to the days when James Lethbridge Brooke Templer was a youngish officer in the eighteen-seventies.

British and world aeronautics owe much to the ceaseless effort of the Farnborough establishment, which has been called by half a dozen names in the course of the years, and has contributed to the flight of every R.A.F. machine and every British civil aircraft moving above the face of the earth. The achievements of British commercial designers and manufacturers, both of merchant and military aircraft, are a source

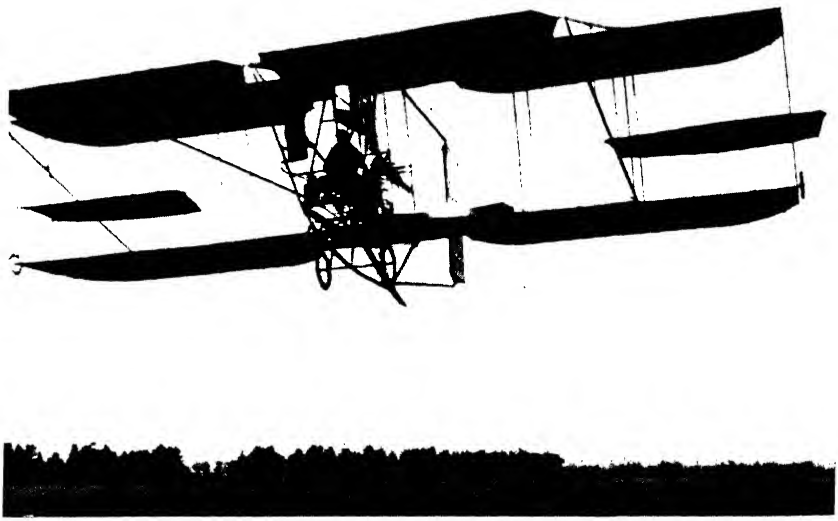


THE FLYING CONTROL TOWER AT FARNBOROUGH with its view of the airfield. The tower is also a laboratory for work on flying control equipment for the precise direction of flying activities.

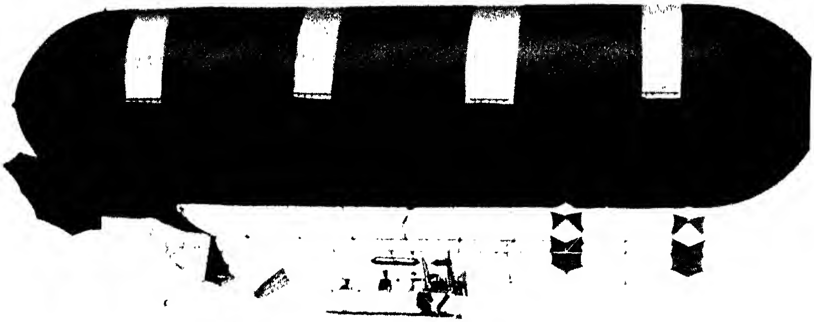




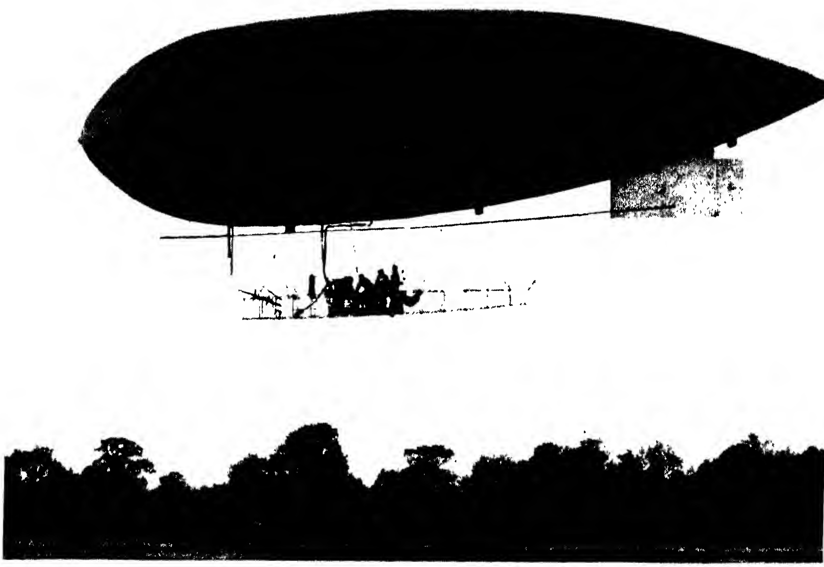
CODY MAN-LIFTING KITE, 1906. S. F. Cody interested the War Office in the possibilities of man-lifting kites of his own design. Work in connection with them was carried out under his direction at Farnborough ; his picturesque mounted figure sometimes brought into the Hampshire landscape a note of the Wild West.



CODY AEROPLANE. This machine is a development of the first Cody biplane of 1908, which was known as British Military Aeroplane No. 1. All Cody's aeroplane work was done at Farnborough. From the airfield there, on October 5th, 1908, he made the first official aeroplane flight in Great Britain, achieving a distance of 496 yards.

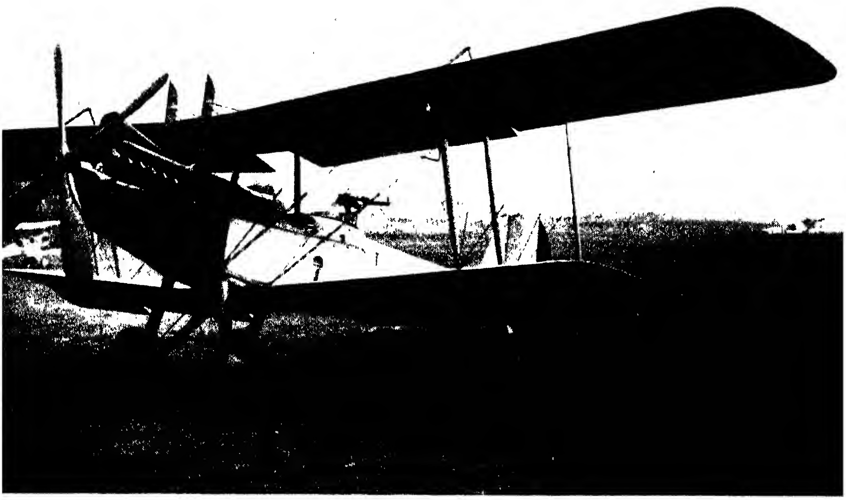


"NULLI SECUNDUS" AIRSHIP, 1907. Constructed by Colonels Templer and Capper at the Factory between 1903 and 1907, this airship was also known as British Military Airship No. 1. On October 5th, 1907, she made a flight from Farnborough to the Crystal Palace in 3½ hours at an average speed of 16 miles per hour.



"BETA" AIRSHIP, 1910. This was a reconstruction of an earlier and smaller airship—the *Baby* of 1909, built by Colonel Capper. The envelope was of goldbeaters' skin, the substance previously used for many years for balloon envelopes. Very successful for her size, *Beta* took part for some years in Army manœuvres.

B.E.2C AEROPLANE. A design evolved from the original B.E. (Blériot Experimental) biplane of 1911, this aeroplane became a widely-used general purpose machine in the early period of the first world war. Some two thousand machines of this type, equipped with the R.A.F. 1b engine, were made in industrial workshops.



R.E.8 AEROPLANE. A development of the original R.E. (Reconnaissance Experimental) biplane of 1912, upon which was done the fundamental work relating to inherent stability. Made in large quantities and equipped with the R.A.F. 4a engine, R.E.8 was the standard artillery observation aircraft in the first world war.

of pride to their countrymen ; and behind those achievements stands the community of air specialists at Farnborough. From balloons and airships they graduated to heavier-than-air machines ; but only rarely have they been called upon to design a complete aeroplane. They have acted rather as consultants, and since 1916 their activities as designers have been restricted to directions largely unexplored by the aircraft industry.

There is, then, a thread of continuity which can be traced from Templer, surveying from the car of a spherical balloon his traction-engines upon Farnborough Common, to the jet pilot looking down upon those same acres and chatting with casual detachment to the radar-packed control tower. It is a thread of discovery and of perseverance, an evidence of the determination of the British people to be at ease in the air as they have for so many centuries been at ease upon the sea.

In this story it is intended to follow that thread without emphasising detail, pausing here and there amid the great diversity of topics through which it leads. Much of the work at Farnborough has gained a wide reputation ; much of it has perforce been shrouded by " security." The Germans learned to respect the place. They knew its latitude and longitude, but they sent no special mission to destroy it. The only bombing suffered was from one of the " routine " airfield raids in August 1940. A German scientist whose views were consulted while the story was being written declared that he had always been against wiping out the Establishment.

" We hoped to occupy it in due course," this German Boffin said, with a reflective smile, " and I was looking forward to the job."

He is, in fact, occupying it, though not perhaps in the capacity he had intended. " Farnborough " has absorbed several of the brains against which in the long dark years its own brains were pitted. They use neat benches, dislike the British habit of smoking while at work, and with apparent contentment and objectivity pursue the study of aeronautics in this vast laboratory which in the days of pony-traps was still Farnborough Common.

TWO

THE WINNING AIM

There will be fights in the air with wind-guns and bows and arrows.

HORACE WALPOLE

All the land shall be compassed as a plain.

ZECHARIAH

"YOU may say that surely there were half a dozen really outstanding things which were done and people who did them," writes a former Director (1942–45) of the Royal Aircraft Establishment, W. S. Farren, C.B., M.B.E., F.R.S. "But the place did not suddenly come into existence for the purpose of plugging one particular line of extreme interest and significance. It grew up, over a long period, and it comprised the key activities of certain essential aspects of all sides of aviation.

"Many, indeed nearly all, of these did not take the form of epoch-making discoveries by exceptionally original and able men. Much of the work was exceptional and many of the men were able, but they worked as part of a team (and were proud to do so), of which the other members were their friends in industry. Their achievements were therefore inseparable from those of the industries with which they worked, and they would feel uncomfortable if a claim was made for them that their own part deserved greater credit than that of their friends."

With such words in mind it may be of interest to follow the course of two particular achievements—achievements which hinged upon Farnborough, but were shared by interests and individuals outside. They were jobs of great importance in the recent war, contributing directly to victory. One relates to air gunnery, the other to navigation.

Combat between aircraft in the air—foreshadowed with prophetic sorrow in the eighteenth century by such diverse philosophers as Horace Walpole and William Cowper—became a reality during the first world war. It began as a simple and chivalrous affair, one airman firing at another first with shot-guns, then with single machine-guns. The encounters were of a personal nature ; knights of the air flew to drop wreaths upon the scene of an enemy's downfall. However, the first world war rapidly developed less romantic aspects of air-gunnery ; the individual duellist gave way, as we all know, to gunners serving automatic weapons mounted upon aircraft.

During the ensuing years of peace, when the science and art of aeronautics was developing, air gunnery stood still. The beliefs at the

time were that at the high speeds which were coming combat during manœuvre would be impossible ; that firing would therefore be almost entirely in stern chase conditions in which few gunnery allowances would be made, and that these could be attained by guesswork. Allowances in air gunnery take into account such factors as the relation between the gun and target motions and gravity ; the gun must not be pointed exactly toward the target for a hit to be obtained, as any sporting gentleman would agree who might go rabbit-shooting in a motor-car.

When, about 1937, guesswork was abandoned, and the need for exact assessment of allowances forced itself into the field of practical air gunnery, the designers of aerial armaments were faced with a new problem. Tracer ammunition had been used widely in the first world war ; and some hope was still entertained that with " tracer " and a fixed sight gunners would be able to make their own estimate of the three allowances—that is to say, of relative speed between target and aiming platform, of trail due to windage, and of the effect of gravity. This hope was soon abandoned, however, and the only salvation for a man engaged in high-speed aerial combat was recognised to be some form of predictor sight.

As early as 1936 a mathematician of exceptional ability, Dr. L. B. C. Cunningham of the Royal Air Force Education Branch, had been pointing out to his pupils that the problem of aiming allowance could be resolved automatically in a simple and elegant manner by the use of a gyroscope to offset the sight line from the gun line through an angle determined by the rate of turn of the sight line. Dr. Cunningham was listened to with interest, but his theories had not found practical expression.

Realistic tactical exercises carried out by the R.A.F. from Northolt in 1938 focused the immediacy of the need for predictor gunsights in aircraft. Until the Northolt trials, the Air Force had been carrying out gunnery tests against towed flag targets at annual practice camps. Upon this occasion, however, Sir Henry Tizard's Committee for the Scientific Survey of Air Defence arranged that a scientist from Farnborough should follow the exercises to advise on points of scientific importance which would otherwise pass unnoticed. The scientist from the Royal Aircraft Establishment made use of cine-camera gun methods in assessing the work of aircraft in mock combat. The specialists were able to see that, even in the comparatively favourable conditions of peace-time exercises, aiming accuracy was poor. It was obvious that predictor gunsights must be found if improvement in aerial gunnery was to keep step with the developments of modern aircraft.

Accordingly, in the autumn of 1938, orders were given for a concentration of effort upon the production of predictor gunsights ; in the experiments which followed can be seen the beginnings of a develop-

ment which matured in Britain during the course of the war, and became of inestimable value to both British and American airmen. That value ultimately made itself felt during the invasion of Europe ; the full development of the sight was probably a decisive factor in the part played by airmen in repulsing that last effort of the Third Reich, the offensive in the Ardennes.

In 1938, however, the improvement of air gunnery presented to scientists, airmen, and manufacturers a problem of great complexity. This problem was naturally brought before the Establishment at Farnborough ; it was treated according to the standard rules for new projects, and placed on the programme as an ordinary research item. Theoretical investigations were carried out and experimental sights of different designs made during 1939. One was tested in a Hurricane ; another, in the under-turret of a Wellington, in April 1940. The results obtained in these early trials were promising, although the experimental sights were of primitive construction, and it was apparent that re-design would be necessary before substantial quantities could be made available for Service use.

After some months of war it became more and more evident that the high-speed performance of combat aircraft would make it vitally necessary to improve the technique of gunnery both for fighters and bombers ; the gyro gunsight project was given special priority, and a team was formed to concentrate upon it.

The theory of the predictor sight, it should be explained, was to enable the gunner to attain a correct aim-off from his target by entirely mechanical means—to have his aim computed not by guesswork, but by automatic instruments.

This theory had already been given practical expression, and the new team was to evolve immediate designs suitable for large-scale manufacture and general use in Service aircraft. It was, moreover, essential that the production model could be applied with slight modification to either fighter or bomber aircraft. Details of the final Mk. I design were completed during the summer of 1940 ; by early autumn two installations, one for fixed forward-firing guns in a Spitfire and one for free guns in a Defiant turret, were ready for trial by the Royal Air Force. Although normally no such innovations can be accepted by a Fighting Service without exhaustive test, the urgency was such that large-scale manufacture was initiated without waiting for the results of the trials. As soon as the first sights were ready they were sent to the Services for trial, and, as will be seen, there was in the beginning a measure of honest doubt in the reports :

September 1940 : " It is the opinion of the Gunnery Research Unit that the true value of the sight cannot be proved without operational trials, and that the way to find out its value is to equip a number of squadrons of aircraft with it and to let the pilots, after receiving all the advice that can

be given to them, find out for themselves to what extent it aids them in actual combat. . . ."

"Trials which have been made with the sight in a Spitfire have led to the conclusion that in its present form it will not be of much value in fighter against fighter 'dog fights' because of the very rapid changes of range and allowance. . . ."

"It seems certain that if the war continues long enough, both sides will be forced to introduce the predictor system in one form or another to outdistance or avoid being outdistanced by the enemy. The introduction of this principle for general service will be accompanied by all the delays and difficulties inseparable from the introduction of any new and hitherto untried principle and it is therefore imperative to begin getting experience in actual operations at the earliest possible date. . . ."

"It is recommended that production should proceed on high priority with the object of putting into action as soon as possible a number of squadrons using both fixed and turret guns, sufficient to give the principle a thorough trial under operational conditions."

Some of the difficulties in introducing such a revolutionary new fighting weapon in the midst of active warfare are recorded in the following extracts from a report made by the Commander-in-Chief, Fighter Command, after trials of the gyro sight in twelve operational Hurricane and Spitfire aircraft during the summer of 1941 :

"The initiative and interest shown in these trials has been far from satisfactory owing to the following reasons :

The difficulty of carrying out Service trials of a gunsight under operational conditions owing to the reluctance of pilots to use an experimental sight for operational purposes.

The restriction that the sight should not be used on operations where the possibility existed that the sight might fall into enemy hands.

It is, however, considered that sufficient information has been obtained from these trials to enable certain conclusions to be arrived at, and that no useful purpose will be served by continuing the trials in Fighter Squadron aircraft.

The conclusions reached as to the effectiveness of the sight are as follows :

The hard and angular nature of the sight in the position it occupies in the aircraft would constitute a danger of facial injury to a pilot in the case of a forced landing, a fact which results in a natural objection on the part of pilots to the sight.

The amount of eye-freedom is very limited, and it is necessary to place one eye to the sight aperture, so that it is not possible to observe other aircraft which would be within the normal field of vision of the eye.

The sight is too sensitive. It requires some device to damp the sudden and violent changes in the position of the moving graticule caused by bumps or alterations in the rate of turn or estimate of deflection.

Rates of turn above rate 2 cause the moving graticule to disappear entirely, and on reappearance it takes one or two seconds to settle down.

The sight cannot be used for night operations in its present form.

It is therefore considered that in its present form the gyro sight Mk. IA is not a practical proposition for the operational requirements of fighter aircraft, and it is recommended that consideration should be given to the development of a reflector sight embodying the principle of the gyro sight, in which case a number of the disadvantages referred to above would be eliminated.

The value of the gyro sight Mk. IA for the training of pilots at Operational Training Units in the correct amount of deflection to be applied in air fighting has been considered, and it is proposed to allocate a number of these sights to Operational Training Units of this Command."

The Royal Navy, making trials about the same time, recommended :

" That the sight should be available to all Fighter Squadrons but that its use should be optional, the choice being left either to Squadron Commanders or to individual pilots."

Coastal Command, making trials late in 1941 and early in 1942, concluded :

" That the provision of gyro gunsights in Coastal Command is an operational requirement for the following reasons :

The sight is mainly suitable for day firing, and the large majority of air combats and gunnery carried out by Coastal Command occurs by day.

It is much easier with this sight to train gunners initially and to keep them in practice.

The scores of practices have improved by 50 per cent. when using the gyro gunsight."

Meanwhile the Farnborough team had continued its work and had produced designs for a new, Mk. II, gyro sight which offered such advantages over the Mk. I that it was decided to build two new factories in the North of England especially to make it.

New manufacturing and testing techniques had to be devised, since the instrument was so novel in conception that there was no previous experience to draw on. This called for continuous and very close collaboration between Farnborough and the production factories in the North, and, as will be seen later, with the American factories.

Before the sight could be used on a Service scale it was also necessary to devise ways of installing the sight in existing Service aircraft, methods of training pilots and gunners, and details of maintenance procedure ; in each of these directions the Farnborough team was called on to assist.

By the end of 1943 the first British Mk. II sights were coming through, and Fighter Command tried out gunsights with four experienced and two relatively inexperienced pilots. From their reports are taken these remarks :

" I look back on previous combats where the enemy aircraft has escaped more or less intact and realise that I could most certainly and easily have destroyed it if I had been using a gyro gunsight."

" An excellent sight which if issued to day fighters should lead to vastly improved combat results."

" This is obviously the sight that fighter pilots have been awaiting."

Two experienced pilots of the United States 8th Army Air Force commented:

> "I believe this sight would improve gunnery at least 100 per cent. Shooting at the moment is, for most pilots, pure guesswork. A pilot cannot guess with this sight and due to this I am sure that at least the lower bracket of pilots (75 per cent.) will improve their shooting to the level of the best gunnery shots now, and the best ones can do even better. It is easy to handle and there is no situation that it cannot handle as well as the G.M.2, and in most cases (90 per cent.) it will do a lot better. Buy me one."
>
> "Speaking from the point of view of the day fighter, I would say that Mark II gyro gunsight is definitely the answer to our problem of deflection shooting. We are proving daily that the average pilot cannot do deflection shooting, even small angles, accurately with a fixed sight. I think this sight should be put into production immediately and fighter squadrons equipped with them as soon as possible."

The British gyro gunsight was formally accepted by the United States Army and Navy authorities and became standard equipment throughout the victorious Allied Air Forces. The ideas initiated at Farnborough in the late thirties became universal and international. Credit for those ideas could not be ascribed to any one individual or even to any one group. They grew from disinterested scientific thought and inquiry, the results of which were made available to the aircraft industry. Their application resulted from team-work between scientists and practical airmen, and there was no better setting for such work than the Establishment at Farnborough, which is an aeronautic laboratory built around an airfield. The story of this achievement is therefore a good example of the truth of Mr. Farren's remark: "Much of the work was exceptional and many of the men were able, but they worked as part of a team. . . . Their achievements were therefore inseparable from those of the industries with which they worked."

Turning now to the development of navigation instruments: during the war the Royal Aircraft Establishment's work in this direction was paid a tribute of which the Establishment was unaware at the time. The tribute was paid by the Luftwaffe Operation Staff in their report on the methods of British navigation made in February 1944, as follows: "Our opponents fully appreciate the limitations of radio navigation and have, therefore, developed navigation by dead reckoning to such a degree that, by introducing other supplementary aids, they are able under all conditions to adhere to the prescribed time schedules when out on a raid, and to reach their targets." The report goes on to say: "British navigation appears to have obtained such a high degree of efficiency that improvements on existing navigation methods can hardly be expected in the near future." If it had not been for work done at Farnborough, that report might have been in a different

vein. However, we had better begin at the beginning, for nearly all navigation instruments were born at Farnborough.

Before the first world war, aerial navigation was practically non-existent. When some adventurous pilot managed to coax his aircraft over the end of the runway and out across the open countryside, he could only tell where he was going by looking over the side at various roads and rivers and checking up with a map on his knees. In April 1913, when No. 2 Squadron at Farnborough flew to their new aerodrome at Montrose, the 450-mile journey took nine days and the aircraft had to land frequently so that pilots might inquire the way—like some motorist on a Bank Holiday trip.

As a matter of exact record, nine landings were made between Doncaster and Newcastle, a distance of only one hundred miles.

The magnetic compass was the first navigational instrument to be used in an aeroplane. Early models proved to be most unreliable, since it was necessary for the aeroplane to remain perfectly steady in the air before the compass would read correctly. Any vibration caused the needle to rotate (later on this fault was eliminated by supporting the compass bowl on horse-hair or other material to damp the vibration).

Errors occurred whenever the magnetic needle was not horizontal, in other words when the aircraft was turning or banking, but as a result of experiments in 1915 by Keith Lucas the causes of this Northerly Turning Error, as it is called, were identified and effect minimised in the subsequent Mark II compass.

By 1918 various methods had been evolved for measuring the drift of an aeroplane. H. E. Wimperis, at Farnborough, produced a wind gauge containing a drift slide. This was followed by a periscopic drift sight which enabled drift measurement to be made without leaning out of the cockpit.

But these liquid-filled magnetic compasses were simple instruments placed in view of the pilot, and, as mentioned above, their indications were of value only during straight and level flight ; they also suffered magnetic interference from the undercarriage and engines, and often from bombs and cannon which were near the pilot's cockpit. Finally, they were not capable of transmitting their readings to a repeater compass or other automatic equipment situated in other parts of the aircraft. In addition to the magnetic compass, the pilot was provided with a directional gyro, but this instrument, although satisfactory under all flight conditions, would slowly wander off the correct heading and manual re-setting was necessary at frequent intervals.

Thought was soon turned towards the development of automatic gear for navigational aid, and in 1932 the first model of the distant reading (or D.R.) compass, developed at the Establishment by the late I. C. Bygrave, was made. This instrument was the answer to the

directional gyro's slow wandering off from the correct heading; a magnetic compass was used to correct it, so that the pilot did not have to re-set it repeatedly during flight. Both these units were incorporated in a master unit which could be installed in a good magnetic situation and was accurate under all flight conditions. However, only a few instruments had been made by 1938, when the Automatic Telephone and Electric Company collaborated with the R.A.E. to put this D.R. compass Mark I into production to equip the rapidly expanding R.A.F. Not till 1940 was quantity production of D.R. compasses started; in that year the first were installed in Stirlings of No. 7 Squadron, R.A.F.

Meanwhile, an idea of Group Captain H. L. Reilly for measuring true airspeed was submitted to the R.A.E., and the air mileage unit, the airman's equivalent of the seaman's log, was designed.

At the same time, a design was prepared at Farnborough for an air position indicator which gave the aircraft's latitude and longitude, an equipment which eventually became standard in Bomber and Coastal Command and was the first automatic deducted reckoning gear to be used in the war. The equipment was accurate within 1 to 2 per cent. in any flying, including evasive action, and was of special value in raids requiring accurate navigation which it was essential should not be upset by enemy counter-measures. These instruments were fitted in the R.A.F. and U.S. Air Forces' Liberators which broke the Möhne and Eder Dams and which led the formation across the Mediterranean to bomb so successfully the Ploesti oil fields.

By 1944 work had been started on a miniature air position indicator and ground position indicator for use in Fleet aircraft in the Far East, but the Japanese war came to an end very suddenly and the instrument was never used operationally. However, work on these instruments has continued, and successful flight trials are now being completed.

During 1943 a new wind-finding technique was tested at R.A.E. in which the aircraft flew over a closed ground circuit of about three minutes' duration, during which the change of air position showed what is known technically as the "windage." This method of wind-finding was made possible by the accurate air plot maintained by the air position indicator, and some open-scale dials were provided to enable the change in air position to be read with more accuracy than was possible on the air position indicator itself. The wind-finding attachment was of special value where very accurate bombing was required, such as in the raid on the Walcheren Dykes towards the end of the European War. To ensure that the main bomber force should be provided with accurate wind information over target areas, fast aircraft were sent ahead with wind-finding attachments to make the actual wind measurements, which were then passed by radio to the main force.

To-day the Farnborough staff are engaged in new developments in instruments for navigational aid, to secure greater accuracy and the elimination of delicate moving parts ; a small robust magnetic detector, which may be installed in the wing-tip of an aircraft, is another of the subjects now under test.

Work at Farnborough has progressed a long way since the days when men guided their aircraft by following the roads on a map. The pilot of the modern bomber, flying through heavy cloud at 25,000 feet over Europe (and seeing nothing from his windows but a sea of undulating and unpleasant vapour), feels a sincere gratitude to the men and women of the Royal Aircraft Establishment as he watches the fine instruments before him. To him they mean that he will see his own pleasant land at the end of his journey.

THREE

HER MAJESTY'S BALLOONS

Away !—away !—the bubble fills—
Farewell to earth and all its hills !
. . . My wife is getting very small !
I cannot see my babe at all !

THOMAS HOOD

THAT the idea of man's becoming airborne is no novelty, confined to our age or our nation, is apparent to any student, say, of the prophet Ezekiel or of the elegist Tsu. The practical attainment of flight, however, called for a new coherence of ideas, and in this country it has been the aim of the enterprise to whose record these pages are devoted to give that coherence to the science and art of flying. For practical purposes it is convenient to refer to this enterprise as the Establishment at Farnborough ; it had several geographical sources, and has borne several names, while retaining an unique thread of continuity throughout the years in which flying has been a reality.

Not the least satisfying element in this continuity is that it exists among people as well as in the realm of ideas. Many men and women working at Farnborough have spent their whole lives in the place. Women who made the envelopes for the first dirigibles have lived to apply their expert skill to materials for the deck-landing of jet aircraft upon modern battleships. Such a famous pioneering name as Cody, so closely associated with the place in the past, is still current. Cody's son and his son's son are employed at the present day in these laboratories of British aviation.

In exploration of early sources, it would be proper to evoke the shade of George Edward Grover, that whiskered and industrious Lieutenant of the Royal Engineers who was instrumental in securing a British Government's first participation in aeronautics. Toward the end of 1861 he wrote a paper urging that the War Office should conduct experiments with balloons in order to ascertain their military value. The next year he read a paper at Chatham, reviewing the successes of balloons used during the French Revolutionary Wars and by the Austrians during the siege of Venice in 1849. He ended his discourse with some rhetorical questions:

> "The main question to be decided appears to be—are balloons capable of rendering sufficient service to an army engaged in active operations to make it worth while to authorise their employment as one of the resources of modern warfare? . . . Whether the advantages obtained from the employment of balloons are commensurate with the time, trouble, expense and ordinary difficulties necessarily attendant upon their use?"

His own affirmatives to these questions were enthusiastic, and were examined by the Ordnance Select Committee, which was sufficiently impressed to report that "the subject is no longer an experimental one, there is now no novelty in the idea, or in the application of it." The Committee went on to ask for permission "to place themselves in communication with some experienced aeronaut, and to arrange for two or three ascents to be made in the course of the summer . . . to give Officers skilled in reconnoitring an opportunity of forming a practical opinion of what can be and what cannot be expected from so elevated a place of observation."

This request was not immediately granted. The future of aeronautics was made the subject of a survey conducted through the British Embassies in foreign capitals; the gallant Grover, commenting upon certain of its findings, condemned the proposals of Lieut.-Colonel Baron Ebner of the Austrian Corps of Engineers for airscrew propulsion in balloons "as the weight to be raised (exclusive of machinery) would be about 500 lb., the immense power necessary to produce sufficiently rapid revolutions *would be literally unattainable, whether manual or steam force be employed. . . .*" He continued: "As for the mechanical means employed by nature to raise heavy bodies in the air the great muscular force exerted (in the effort of volitation) is rather an object for the Anatomist to admire than for the Engineer to hope to imitate."

In the following year, 1863, the War Office was persuaded reluctantly to take advantage of the offer of the experienced and persistent Henry Tracey Coxwell (who, incidentally, had already in Germany demonstrated the practicability of dropping bombs from balloons) to make a series of experimental ascents at Aldershot. Accordingly a contract

was drawn " securing that gentleman's services for two or more days as well as the hire of his balloon " at the rate of £30 a day. Coxwell followed ballooning as a profession. He had during the previous year reached an altitude of some 37,000 feet with James Glaisher ; and no doubt the enthusiasm of Grover and his associates, and the possibility of arousing the interest of the War Office, to some extent compensated Coxwell for the unattractive financial arrangements.

The Prince and Princess of Wales were present on that July day in 1863 when a balloon was inflated with coal-gas, and Grover ascended in company with Captain Frederick Edward Beaumont, R.E. Both officers wrote reports, referring, among other things, to " useful results which could be obtained by photography from a balloon." Nevertheless, two years later, the Select Committee was deciding not to recommend balloons for the Army " in times of profound peace." The six years' enthusiastic work of Grover appeared to have been shelved.

The peace, as we all know, was anything but profound ; and the ideas of Lieutenant Grover were not to remain with that officer on the shelf. A proposal was made in 1873 for a balloon to form part of the equipment of the Ashanti punitive expedition, but during those years no satisfactory means could be found of generating gas.

In 1878 emerged the first really representative Farnborough figure in the person of James Lethbridge Brooke Templer, Captain the 2nd Middlesex Militia. He had been at Woolwich Arsenal watching experiments in the generation of coal-gas, and his reputation as an authority on aeronautics must have stood high, for he was approached with the suggestion that he should place his knowledge at the disposal of the War Office. Templer agreed to do so, and the Department allocated £150 toward the cost of building a balloon. An account of the first ascent of this balloon appeared in *The Times* of August 24th, 1878. Templer, though himself a man of means, was engaged at the rate of 10s. a day " when actually employed " as Instructor to officers of the Corps of Royal Engineers in the art of ballooning. What was perhaps of greater importance was that he applied his inventive enthusiasm to experiments in gas generation. The War Office, however, made it clear that the balloon was still not recognised as part of the equipment of the Army.

At the newly created Balloon Equipment Store at Woolwich the experiments went on. During Easter, 1879, when the volunteers held a field day at Brighton, Captain Elsdale, Royal Engineers, who was in command of a Balloon Detachment, took part in the march-past, standing in the basket of a balloon towed at a height of 250 feet from the ground. The next year the War Office conducted tests to find the vulnerability of balloons subjected to artillery fire, and it was decided that it would be unsafe to keep a captive balloon in the air within two

miles' range of hostile batteries. In 1882 Chatham became the centre of military ballooning; in 1883 the *Sapper* was made there, with silk for an envelope. It appears that immediately afterwards Templer suggested the use of goldbeaters' skin for the making of envelopes.

In 1883, the Balloon Equipment Store was established at St. Mary's Barracks, Chatham, a "ball-court" being roofed over and turned into an erecting shop; during the next year Templer reported that if funds were available a complete Balloon Centre could be provided without difficulty. That year a Balloon Detachment actually went abroad, arriving at Cape Town on December 19th, 1884, with five balloons. The *Heron* was inflated at Mafeking on April 6th, 1885. Sir Charles Warren and some of his staff made an ascent next day. The *Spy* and the *Feo* were then inflated, and the new air arm of the British Army proved itself to be of value. The possibilities of aerial warfare were established. There was talk of aerial batteries to be used against the Mahdi outside Khartoum. Templer himself went to Egypt in 1885, after the death of General Gordon. A detachment was sent to Bechuanaland. Wagons were designed capable of holding a winch and a supply of gas-filled cylinders. Experiments were made in photographic reconnaissance.

Templer found on his return from abroad that the balloon work at St. Mary's Barracks, Chatham, was outgrowing its quarters. With characteristic enterprise he solved the problem by buying land at his own expense near his own house at Lidsing, near Chatham. As there was no shed available, sappers dug a pit in the hillside sufficiently deep to house a balloon of 10,000 cubic feet capacity. Records show, and there are still people at Farnborough who can confirm the fact, that Templer was a pioneer who would stick at nothing.

In 1889, a detachment of balloons was sent to Aldershot to take part in the summer manœuvres. The force of which the detachment formed a part moved out from Aldershot to capture a mobile column of the enemy which was camped near Frensham Ponds; the balloonists were asked if the enemy had outposts in the rear of his camp. Their reports were so accurate that Lieutenant-General Sir Evelyn Wood, V.C., reported to the War Office that balloons were likely to play an important part in the campaigns of the future. At the same time he recommended that the Balloon Establishment should be moved from Chatham to Aldershot, in order to make sure that the potential air weapon should be familiar to the Army. The following year, 1890, therefore brings the story to its beginning so far as Farnborough is concerned. In the Army estimates that year a Balloon Section was authorised as a unit of the Corps of Royal Engineers. Major Templer, having become "Officer in charge of Balloons," began to remove the Establishment from his own land in Kent and to supervise the erection of buildings on the outskirts of Aldershot near the canal.

During the nineties, the staff of the Balloon Factory (its current name) was concerned mainly with experimental work, an important part of which was the generation of hydrogen. During the latter part of the decade the question of man-lifting kites was raised, a subject to which we will refer later. Templer still reigned supreme.

At the outbreak of the second Boer War in the autumn of 1899, the Establishment supplied balloons, with trained sappers, to accompany the expeditionary force. Three detachments went to South Africa ; and the verdict of the military authorities upon their activities was on the whole not flattering. The new air weapon, it seemed, had a greater moral than military effect. Colonel Arthur Lynch, who served with the Boers, afterwards referred to the British balloons in these terms:

> "The Boers took a dislike to the balloons. All other instruments of war were at their command ; they had artillery superior for the most part to, and better served than, that of the English ; they had telegraphic and heliographic apparatus ; but the balloons were a symbol of a scientific superiority of the English which seriously disquieted them."

During that war the normal output of the factory was increased from one balloon to two balloons a month, and considerable additions had to be made to meet the demands. Already there were undercurrents of experiment in the direction of such novelties as non-rigid airships and man-lifting kites. After the turn of the century, Colonel Templer visited the Brazilian pioneer Alberto Santos-Dumont in Paris to report on small non-rigid airships. Templer recommended experiments, but economies had set in and the factory estimates were halved from £12,000 to £6,000.

Nevertheless—it is not recorded by what means—the indomitable Templer persuaded the authorities to give him permission to begin making experiments with non-rigid airships. A wealth of information and resource was already accumulated ; the factory staff was starved of materials, but not discouraged by set-backs. Already events were overtaking the reactionaries. If Her Majesty's Balloons were a lesser triumph of the great reign, if they had perplexed the conventional soldiers and occasionally disappointed the enthusiasts, their achievements had stimulated the growth of ideas, and had brought aeronautics into the life of the nation.

FOUR

THE COSMIC EYE

We are able to judge man in cosmic terms, scrutinise him through our portholes as through instruments of the laboratory.

ANTOINE DE SAINT-EXUPÉRY

RECONNAISSANCE was very quickly recognised as one of the most valuable possibilities connected with flight. Had not Grover and Beaumont, after their ascents of the eighteen-sixties, recommended photography from a balloon ?

From the painstaking air views taken by plate cameras in those early days to the hectic month of August 1944, when No. 1 Photographic Reconnaissance Unit of the R.A.F. produced a quarter of a million negatives and half a million prints during the battle of Normandy, the theory of air photography was steadily studied at Farnborough. It is doubtful whether, before the second world war, anyone had quite visualised the potential value of air photography as a means of intelligence. Certainly nobody foresaw that over 80 per cent. of all of our intelligence of the enemy would be obtained in that way, and that for a time after the fall of France, before the underground movement had had time to organise espionage, the air-photo was to be practically our only source of intelligence.

There had been little development of air photography between the two wars. In the thirties it had been assumed that aircraft taking reconnaissance pictures could fly at heights between 5,000 and 15,000 feet. A pre-war camera, the F.24, originally designed at Farnborough in the late twenties, was eminently suitable for such work. After only a few weeks of war, however, it was found that the photographic Blenheim, flying unescorted at 10,000 to 15,000 feet over heavily protected enemy territory, had little chance of survival. It became evident that only from fast high-flying aircraft would good enough results be obtained to satisfy the three Services. A forecast to this effect had, in fact, been made to the Air Ministry in 1935 by a small group of research workers " bitten by the bug " of air photography in the first world war, and themselves quite convinced of what another war would demand of photography. At that time, however, their ideas were considered premature. Nevertheless it was because such individuals had been considering every application of photography between the wars that theory, at least, was well advanced and ready for the emergencies of 1939.

About a month after the outbreak of war, a damaged Spitfire

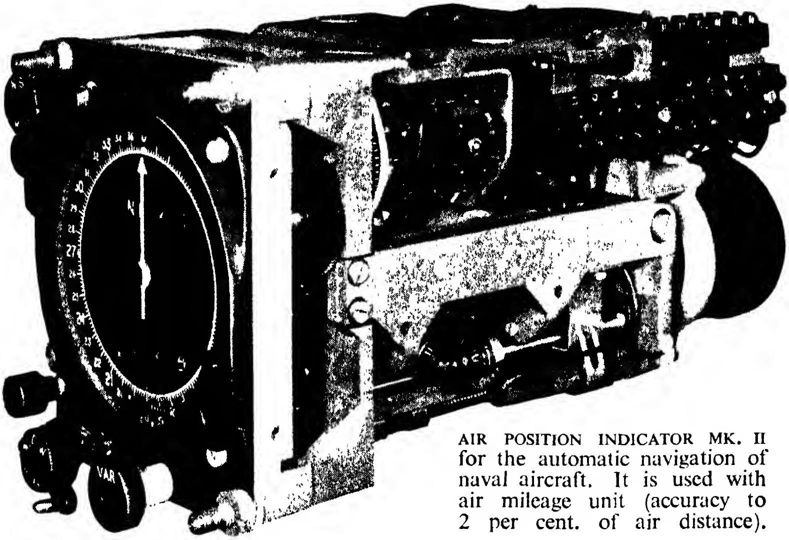
undergoing repairs at the Establishment at Farnborough was installed with a F.24 camera in place of the flare chute. After tests in October 1939, and further installations with two cameras, one in each wing, the first operational sortie was made on November 18th with Aachen as a target. The fact that navigational difficulties caused the pilot to make a reconnaissance of Eupen (then on our side of the line) did not detract from the success of the venture. The next two sorties covered the Siegfried Line correctly ; the tenth sortie covered the whole of the Ruhr area.

This new experimental aircraft operated from Heston, but the films were processed at Farnborough under conditions of great urgency and secrecy. The success of these first war pictures of enemy territory put a heavy strain on the technical staff ; it was not unusual to see the head of the Photographic Division, after working all night, batching and sorting prints in the early hours of the morning. In fact, the experts at Farnborough fulfilled an important operational function until the formation of the first Photographic Development Unit of the R.A.F. This unit began by operating at Heston, under the guidance of the Establishment, before becoming embodied in the middle of 1940 as Photographic Reconnaissance Unit, famous and indispensable handmaid of Allied Staffs upon every front throughout the world. The Farnborough Photographic Division's report favours a nursery metaphor in describing their own relations with the new unit :

> " The PRU was thus born and weaned here, and for the first two years of the war occupied much of the attention of the Photographic Division. Thereafter it became a little independent and treated us like ageing parents : but it has never been too proud to come back with its troubles. It was certainly a most difficult child to rear and conditions could not have been more unfavourable."

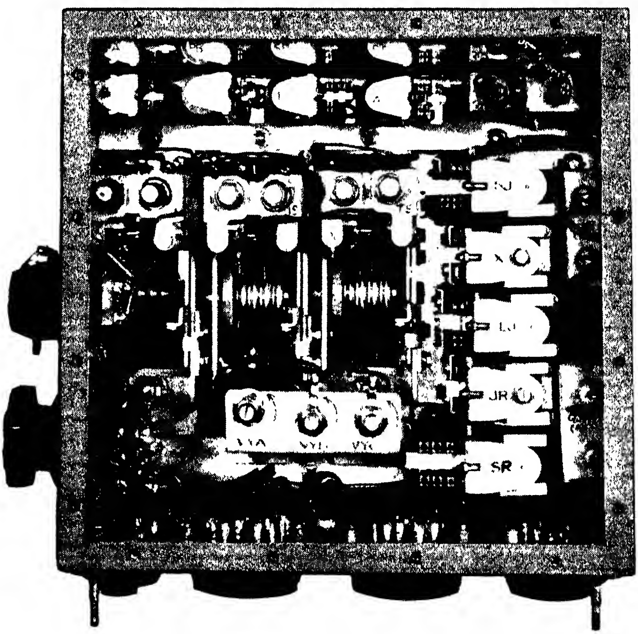
The theory of high reconnaissance being established, the first problems were those of installing cameras in the machines. The height at which the Spitfires were to operate brought them into temperature zones so low that the film base became too brittle to spool, the camera mechanism stiff and distorted, and the operating batteries non-effective. Moreover, the speed in climbing and descending produced rapid temperature changes. In a dive, for example, from 30,000 to 3,000 feet, for the purpose of taking pinpoints of a target, the change could be as great as 50° C. in six minutes, resulting in condensation and frosting over the camera lens, completely destroying the image. The first attempts to overcome these difficulties made use of electrically-heated lagging and sealed camera apertures, but these were eventually superseded by a sealed camera bay, heated by air which had passed over the engine radiator.

A greater difficulty in this pioneer air reconnaissance work was the fact that the scale of the photographs made at 30,000 feet, with

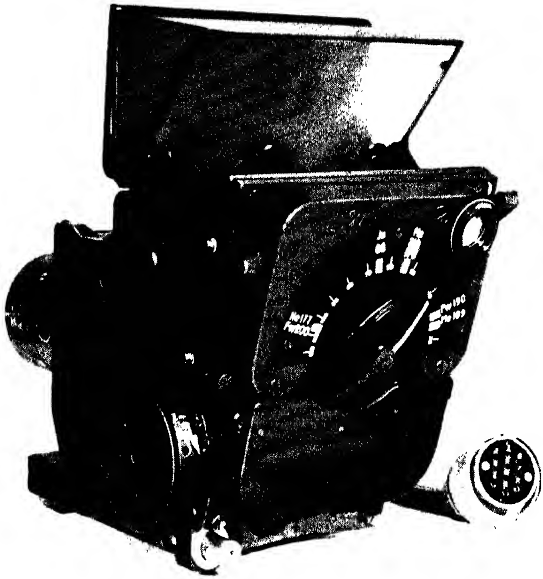


AIR POSITION INDICATOR MK. II for the automatic navigation of naval aircraft. It is used with air mileage unit (accuracy to 2 per cent. of air distance).

24-WAY BOMB RELEASE DISTRIBUTOR, a type of instrument which in various forms played an important part in the achievement of accuracy by bombing missions. The two pieces of apparatus illustrated on this page are examples of the Establishment's complex ancillary work that goes to the making of a complete aircraft.



GYRO GUNSIGHT. A considerable amount of pioneer and subsequent development work at Farnborough eventually resulted in the production and use of the gyro gunsight during the latter part of the second world war. Accuracy of shooting, even by average pilots, was very materially increased by its use.

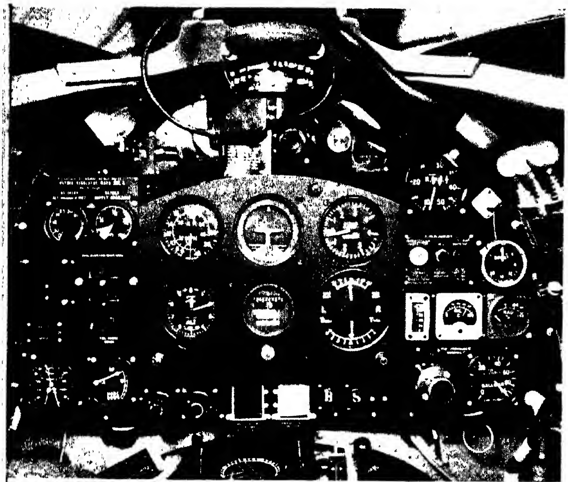


Left :

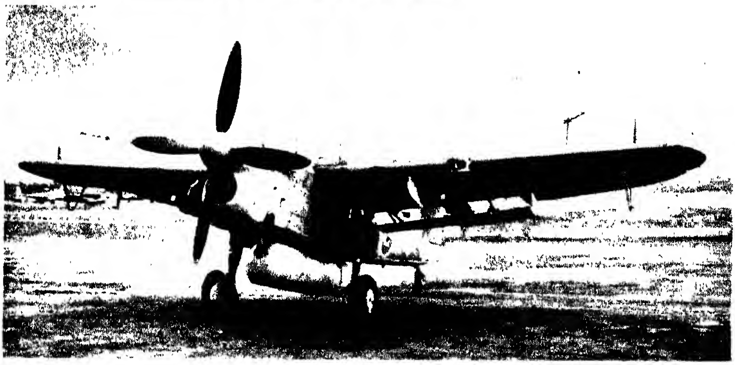
SYNTHETIC TRAINER. In this device, used for training rear-gunners to use the gyro gunsight, the image of a moving aeroplane is projected on to the realistically - coloured plaster surface of the "sky."

ROCKET PROJECTILES. These weapons, of which the development was based upon work performed at Farnborough and at various land and under-water ranges in other parts of the country, had a profound influence upon Allied tactics towards the end of the second world war. They gave to a fighter aircraft the hitting power of a light cruiser's broadside, well illustrated in this picture of an actual attack.

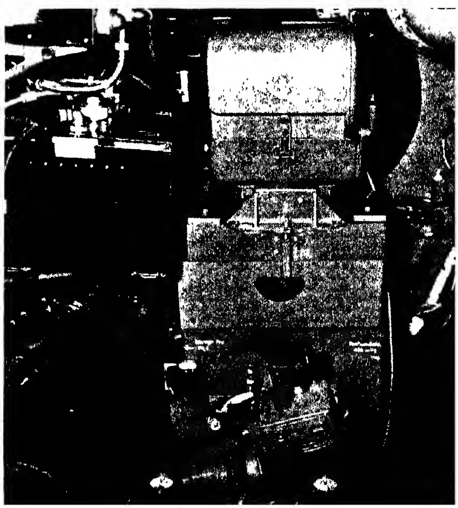
ROYAL AIRCRAFT ESTABLISHMENT, FARNBOROUGH, 1947. The Establishment has occupied its present site since 1905 and traces its origins back to Aldershot (1892), Chatham (1882), and Woolwich (1878). These buildings cover an area of 55 acres. The adjoining airfield, which has been used continuously for aviation for 40 years, has a main runway of 2,400 yards and a total perimeter track of five miles.



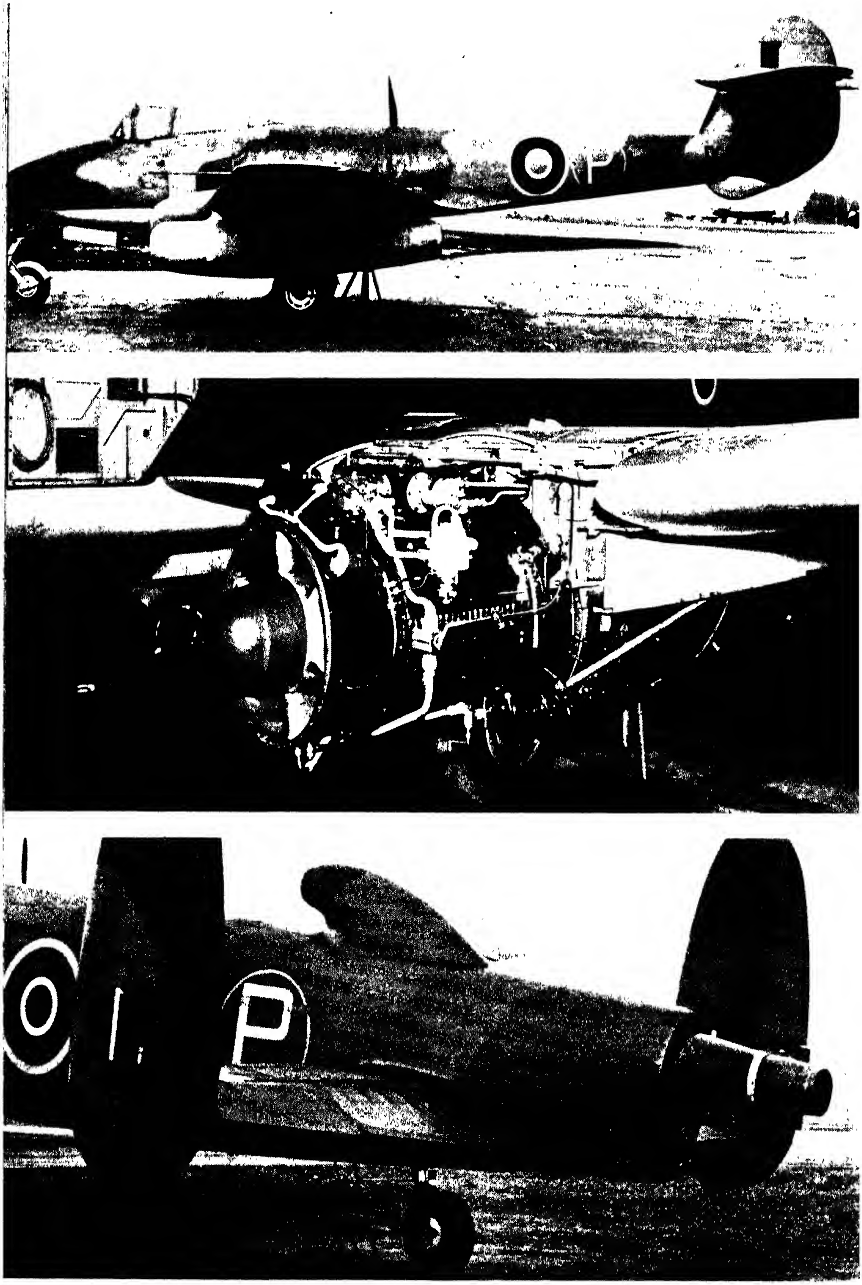
A MODERN FIGHTER COCKPIT AND INSTRUMENTS, the complexity of which is intended to make the pilot's work as automatic and simple as possible, and thereby to reduce to a minimum errors due to the human factor.



SUPPLY CONTAINERS. The technique of maintenance of a force entirely from the air was proved of great importance, particularly in the Burma and Normandy campaigns. Much work on parachute design and general engineering was required to develop this project to a stage of precision sufficient to meet operational requirements.



PHOTOGRAPHIC RECONNAISSANCE UNIT (PRU) FIELD PROCESSING TRAIN AND AIRCRAFT. The need for accurate high-altitude reconnaissance photographs and for rapid field film processing became manifest early in the war ; work on this subject contributed materially to the efficient service eventually made available to all the armed forces. *Above :* a complete mobile unit, and the interior of one of the vans, showing WAAF personnel at work on processing. *Right :* two cameras installed in a PRU Mosquito aircraft, one vertical, the other horizontal.



F.2 GAS TURBINES IN METEOR AIRCRAFT AND IN LANCASTER TEST BED. Gas turbines for aircraft were under consideration at Farnborough as long ago as 1926. From 1938 onwards work proceeded in collaboration with Metropolitan-Vickers on the design of the F.2 axial flow type which now forms the basis for the Metropolitan-Vickers F2/4 engine. Other types were also flight tested, one early method being as shown, with the engine unit fitted into the tail gun-turret position of the Lancaster.

relatively short lenses of 5-inch or 8-inch focal length, imposed severe limitation upon the detail which could be identified by the intelligence officer. This is not surprising when it is realised that a 5-inch-square picture taken with a 5-inch lens at 30,000 feet was covering 32 square miles of ground. A football pitch, therefore, would appear about the size of a pinhead on the photograph. This difficulty was overcome by research and development in lens and camera design, and in the use of improved photographic emulsions.

Apart from a few 20-inch telephoto lenses of 1918–19 vintage, there were virtually no lenses of greater focal length which would meet the new requirements ; three leading lens makers were therefore asked to submit samples of 20-inch telephoto lenses covering a 9-inch-square negative. An interesting point may be noted here which is common to most of the successful ventures undertaken at Farnborough. Not only were the civilian technicians of the Establishment in constant and friendly communication with the photographic and intelligence staff of the R.A.F., but the best brains of the photographic industry were regularly brought into consultation. This co-operation of experts laid solid foundations for what was to be a big enterprise. The R.A.F. was embarking upon photography in such a big way that by 1943 their film and printing paper alone was costing two million pounds a year.

The optical industry supplied the longer focal length lenses, most of which were available by the end of 1941. A larger camera, the famous F.52, was designed and adopted ; and a still further gain in ground cover was obtained by using a pair of these cameras at one time. Probably 99 per cent. of all air pictures have been made on a fast medium-contrast panchromatic film used with a minus blue filter for haze penetration. Pilots upon these highly specialised operations would seldom have time over the target to adjust cameras for exposure, and such adjustments had to be estimated in advance. The conditions were so unlike those of ground photography that only by the slow process of trial and error was it possible to obtain a reliable set of exposure tables, covering conditions in any part of the world. Working in close collaboration with industrial research laboratories, the Establishment staff effected a new system for determining photographic resolution, using low contrast test objects. For air tests, the Photographic Division had its own flying laboratory. A huge test object, looking rather like a rock garden, was laid out as a target on the roof of one of the Farnborough buildings.

The essence of all reconnaissance is speed, and a neat and characteristic demonstration of this fact was made by some of the PRU people when the Americans first arrived and mounted their daylight raids across the Channel. Before lunch a raid on the way out passed over the photographic reconnaissance airfield which the Americans were inspecting. After lunch, a Spitfire dropped down on this

reconnaissance airfield and delivered films; the Americans were able to see prints showing the results of their own squadrons' raid while the bombers were still crossing the Channel.

The taking of high-altitude photographs having been made possible, it was one of the tasks at Farnborough to ensure that they could be handled so quickly that the full strategic and tactical benefits would be derived from them. Clearly it was absurd to send photographs off by dispatch-rider to be processed at permanent bases when the information they contained was of immediate interest; and a true British spirit was displayed in a meeting, held when the Battle of Britain was at its height, to discuss the design of mobile field sections.

Two years after these discussions between the Establishment technicians and the R.A.F. staff, the first of these mobile units went into operation. It consisted of five tenders, self-supporting in water and electrical power, and air-conditioned for any climate. The prototypes, which were built at Farnborough, were in fact rather over-elaborate, and simplified versions became standardised. These were built in industrial workshops and took the field in North Africa, supplying over a million prints a month in the Libyan campaign.

Up to 1941 a single film of 500 exposures took one man anything up to an hour to process and a further hour to dry. By the end of the war the same job could be completed in minutes.

Such was one part of the work of a single section of the Establishment in creating and sustaining one of the most telling contributions to the air war. Not least of the problems in such a vast photographic scheme was to provide equipment which the hastily-trained, the non-expert, the preoccupied, could handle. The two cameras, the F.24 and the F.52, were not only efficient as instruments but also simple to handle, easily adaptable, and, most important of all, they could be mass-produced in the factories of Britain and America.

The photographic experts at Farnborough used their traditional abilities and equipment on other devices too numerous to mention, but their share in the birth and " weaning " of PRU must rank high among their achievements, just as the often-unsung exploits of PRU rank among the most glorious of the war in the air. What next? Those achievements are already history, but the work goes on. An entirely new camera for air survey is now something more than a blue-print. Air survey, which entered the war as a mere supplement to ground-survey and map-making, may well become the standard method for world-wide survey of the globe.

That which was but a thread of thought in the minds of the much-discouraged balloonists, that which assumed a clearer shape when photographs were taken from man-lifting kites in 1904, that which recently became a potent force in air warfare, is now a commonplace tool for use in the universal interests of mankind.

FIVE

THE WHEELS WERE LIFTED UP

And when the living creatures went, the wheels went by them : and when the living creatures were lifted up from the earth, the wheels were lifted up. EZEKIEL

WHEN Colonel Templer puffed at his pipe and everybody watched the smoke to see if the wind would be too strong for the man with the camera in the kite at Farnborough in 1906, the Wright brothers had already fulfilled the words of the prophet and established once for all that man could fly in a power-driven heavier-than-air machine. Work on man-lifting kites had been going on since the nineties ; during the first years of the new century there had been great experimental and training activity covering the whole available apparatus of aeronautics, including spherical and elongated balloons, kites and winches.

In 1904 an associate of Templer's, Colonel J. E. Capper, R.E., went to North Carolina on behalf of the War Office to invite the Wright brothers to England to continue their experiments, but the Treasury would not sanction the necessary expenditure. It was a period of divided opinion. The 1905 edition of the *Manual of Military Ballooning* issued by the War Office contained the following statements :

> "Under certain circumstances, the direction of wind being favourable, a charge of gun-cotton might no doubt be floated out over an enemy's work, and dropped into it.
>
> The charge would be provided with a percussion fuse or it would be fired by means of a dynamo-electric exploder in the car.
>
> Such an operation would have to be carried out in the dusk of the evening or early dawn.
>
> The moral effect produced by the employment of balloons should not be lost sight of in estimating their value for war purposes.
>
> A captive balloon with nothing but sand-bags or a dummy in the car might paralyse an enemy's initiative, and especially might deter him from attempting any wide-turning movement, by causing him to believe that all his movements were being watched."

The value of air reconnaissance was established. Now movement through the air was suggesting to the Services the possibilities of aerial bombardment. But how would movement be attained—by aeroplane, kite or dirigible ?

S. F. Cody, cowboy, actor (like his celebrated and earlier namesake), balloonist, kite inventor, aeroplane designer, and one of the most colourful individuals in the history of aviation, makes his appearance at Farnborough at this point. His name will always be associated with the place. His memorial is in the diversity of important work which

he did, and in his family, which carries on that work as already mentioned. There is also one other memorial which American airmen (Cody was an American by birth) flew to visit during the recent war: this is a solitary dead tree which stands outside the hangars at one end of a great runway at Farnborough. It is called " Cody's Tree," and an inscription records the fact that Cody used it as a picket to tether his aeroplanes.

That, however, anticipates history. In 1904 Cody had just succeeded in interesting the War Office in his man-lifting kites, and two years later he began his official association with the Establishment by being appointed Chief Instructor in Kiting to the Balloon School. Besides his famous tree, there is one piece of the landscape at Farnborough to-day with which Cody would have been familiar. In 1905 the Balloon Factory was moved to the site now occupied by the Establishment at South Farnborough. The first building to be erected still exists as No. 3 Building. It was not new when it was moved; it is interesting to reflect that now, some forty-four years later, it is probably the oldest building in the world to be used continuously for purposes of aeronautics.

When the move was over, Colonel Capper was appointed Superintendent of the Factory as successor to Colonel Templer, who became " Consulting Engineer " with a retaining fee. Colonel Capper believed in the future of the aeroplane. In a lecture given after his meeting with the Wright brothers in America, he had said:

> " There is another and far more important phase of aerial locomotion which in the near future may probably have to be reckoned with. . . . In a few years we may expect to see men moving swiftly through the air on simple surfaces, just as a gliding bird moves. . . . Such machines will move very rapidly, probably never less than twenty and up to a hundred miles per hour; nothing but the heaviest storms will stop them. They will be small and difficult to hit, and very difficult to damage, and their range of operations will be very large."

Colonel Capper was not slow to put his beliefs into practice. He encouraged Cody, who had asked to be allowed to convert one of his kites into a power-driven machine. That permission having been refused by the War Office, Cody went to work on the designs for the layout of the car and power plant of *Nulli Secundus I*, the first dirigible, the envelope of which had been designed and made by Templer in 1904. Capper meanwhile recommended the War Office to purchase any flying machines which should come into the market: and he supported the activities of Lieutenant J. W. Dunne—philosopher and friend of H. G. Wells—who had been attached to the Factory in order to carry out full-scale experiments with inherently stable aircraft.

The first machine was to be a biplane. " It was decreed that the experiments should be carried out with the utmost secrecy," Dunne himself wrote in a letter to C. F. Snowdon Gamble, author of *The Air*

*Weapon.** " The machine was built piecemeal in the shops and the parts were put together by myself and one assistant in a locked room. I was forbidden to wear uniform and my name remained in the Army List as an invalided officer absent on half-pay." When the machine was finished, the War Office sought a secret testing-ground for it. R. B. Haldane, then Secretary of State for War, eventually arranged with the Marquess of Tullibardine, afterwards Duke of Atholl, for the use of a grouse moor near Blair Atholl. In 1907, men were selected from among the Royal Engineers in the Balloon and Kite Section at Farnborough ; they were " put into civilian clothes and made their way unobtrusively to Blair Atholl." Dunne's biplane, D.I., had been stripped after erection at Farnborough and was reassembled at Blair Atholl. It had two motors and no tail, in unconscious defiance, perhaps, of John Milton's description of the mediæval pioneer Oliver of Malmesbury: " so conceited of his art, that he attributed his fall to the want of a tail, as birds have, which he forgot to make to his hinder parts."

The Duke of Atholl, writing to Mr. Gamble years afterwards, gave this report of the proceedings :

> " We made several attempts at diving in a small way and used models by dropping them from cliffs to see how they behaved. They all showed automatic stability. We were all certain that the thing would fly if we could only get it high enough, so eventually one day we took it to the top of a cliff some 2,000 feet up with the idea of gliding over Glen Tilt. It was not possible to put Dunne in it as he was the inventor. We could not afford to lose the head of the Balloon School, so the principal fool being myself—or shall I say the only one ?—it was arranged that I should be tied into it, which operation was performed. Just before starting I looked down and saw a white spot beneath me. On turning my glasses on it I saw that it was a doctor spreading out a ground-sheet and getting his appliances all ready. But an all-wise Providence blew the machine right over, and we never started."

Colonel Capper, however, made one soaring glide in the machine : but afterwards, when the engines were installed, she was wrecked on launching, and the experiments were abandoned for that year. " Security " in Edwardian days was not of that order to which we are now accustomed ; neither remoteness of scene nor secretiveness of preparations prevented the Press from making strenuous attempts to probe the " mystery of the moors," and reporters were only kept at bay by the energy and guile of the Duke of Atholl's celebrated private army.

During the winter of 1907–8 Dunne had another machine made at Farnborough, with a radial engine of 20–25 h.p. in place of the two motors, and with a powerfully sprung undercarriage in place of skids. In the summer there were further trials at Blair Atholl, but these failed.

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* Oxford University Press, 1931.

"The apparatus was able to leave the level under its own power, but a jump of 40 yards was the most that it could do."

So the staff at Farnborough encountered more discouragement. In the spring of the year (1909) in which Blériot flew the English Channel, Dunne and Cody were told that the War Office had decided to abandon work on aeroplanes. The expenditure had been in the neighbourhood of £2,500, and this was considered to have been too great. For the moment, therefore, these two enthusiasts were left to draw what consolation they could from the report that Germany at this time had spent some £400,000 on military aeronautics.

Meanwhile work on non-rigid airships had steadily continued; in the autumn of 1907 the *Nulli Secundus* was ready for her first voyage. She was about 120 feet long, the diameter of her sausage-shaped envelope being less than 30 feet. She was driven by the thrust of two propellers powered by a 50 h.p. Antoinette engine. There was great excitement in the sheds at Farnborough while the staff watched for favourable weather.

Percy Crosson, the present Workshop Superintendent, helped as a young man to build the airship, and he particularly recalls Colonel Capper's fierce injunction to secrecy during the process. The airship was brought out on October 5th, 1907, and, piloted by Capper and Cody, ascended into a clear sky, departing in the direction of London, pursued by several excited officers in almost equally adventurous motor-cars. She passed over the City of London, circled St. Paul's Cathedral, manœuvred over the grounds of Buckingham Palace. The evening papers registered the event with the headline: "BRITAIN MISTRESS OF THE AIR." On her return journey she was unable to make headway against the wind, and descended in the centre of the cycle-track at the Crystal Palace, having been in the air for three and a half hours. A few days later, to save her from being carried away by a strong wind, the ship was hastily deflated, packed up, and returned to Farnborough by road.

Colonel Capper rebuilt *Nulli Secundus*, using much of the old material, as a semi-rigid airship. During her first flight, however, in the summer of 1908, she remained airborne for only eighteen minutes, suffering various mishaps and travelling only four miles. Perhaps her most valuable contribution to aviation was the fact that Cody inherited her engine and used it for experiments on his first biplane.

Another smaller airship, the *Baby*, afterwards enlarged and re-christened the *Beta*, was put in hand, and in 1910 made a successful night flight from Farnborough to London and back, covering a distance of about 70 miles in just over four hours.

The output of Farnborough was small during the years when Britain and the world were standing upon the brink of the new air age. The Factory in 1909 consisted of one small machine shop, one shed for

making balloons, and one airship shed. The workpeople numbered about fifty men and fifty women.

The year 1909 may have seemed one of frustration and disappointment to many people connected with Farnborough. Sir Walter Raleigh has described the situation in *The War in the Air*:

> " The science of aeronautics in the year 1909 was in a very difficult and uncertain stage of its early development; any mistakes in laying the foundations of a national air force would not only have involved the nation in much useless expense, but would have imperilled the whole structure. Delay and caution are seldom popular, but they are often wise. Those who are stung by the accusation of sloth are likely to do something foolish in a hurry. Nothing is more remarkable in the history of our aeronautical development than its comparative freedom from costly mistakes. This freedom was attained by a happy conjunction of theory and practice, of the laboratory and the factory. The speculative conclusions of the merely theoretical man had to undergo the test of action in the rain and the wind. The notions and fancies of the merely practical man were subjected to the criticism of those who could tell him why he was wrong. The rapid growth in power and efficiency of the British air force owed much to the labours of those who befriended it before it was born, and who, when it was confronted with the organised science of all the German universities, endowed it with the means of rising to a position of vantage."

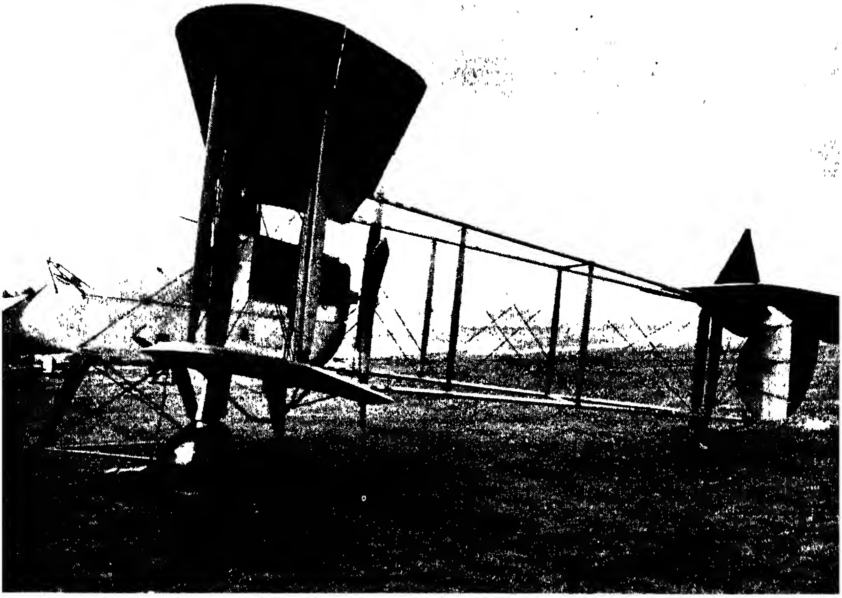
It was partly owing to the energetic representations of Colonel Templer that the Secretary of State for War, R. B. Haldane (later Lord Haldane), secured the appointment of the Advisory Council for Aeronautics, with Lord Rayleigh as chairman, to study the future of the subject. The Council contained and commanded a diversity of talent which found brilliant expression at Farnborough under the leadership of Mervyn O'Gorman from 1910 to 1916; in particular it fostered the activities of the National Physical Laboratory, which organised an elaborate department for the investigation of aeronautical questions in close collaboration with Farnborough. " Mathematical and physical investigations," Sir Walter Raleigh has written, " were continuously carried on at the laboratory, and improvements suggested by these researches were put to the practical test at the Factory. Questions of air resistance, of the stresses and strains on materials, of the best shape for the wing of an aeroplane and the best fabric for the envelope of an airship—these and scores of other problems were systematically and patiently attacked. There were no theatrically quick results, but the work done laid a firm and broad base for all subsequent success. Hasty popular criticism is apt to measure the value of scientific advice by the tale of things done, and to overlook the credit that belongs to it for things prevented."

The Hon. C. S. Rolls had offered, a year or so earlier, to bring to Farnborough a biplane for testing purposes, but owing to an accident to Cody's biplane the ground at Farnborough was officially discredited

as a flying ground, and the acceptance of Rolls's offer was deferred. He renewed it in the spring of 1909, and the War Office accepted the gift and built him a shed. Rolls had started to make some test flights and to give instruction to interested officers when he met his death at a Bournemouth aviation meeting. "Had he lived," writes C. F. Snowdon Gamble, "there is little doubt that he would have arranged for his firm (Rolls-Royce Ltd.) to build aero-engines earlier than it did, with the result that progress in British aviation would probably have been more rapid, hampered as it was at this period by inefficient foreign-built engines."

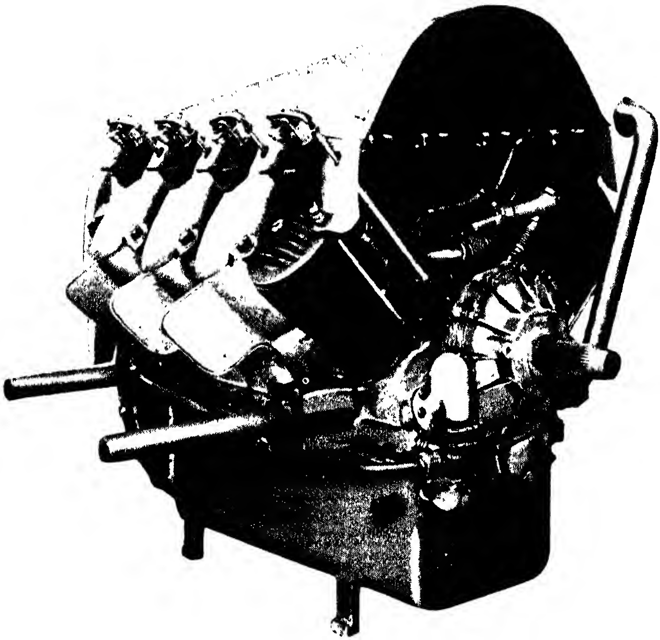
The era of intensive research in all the most important aspects of the design and construction of heavier-than-air machines really began in the year 1910. Though starved of resources and meagrely supported by Government grants, the factory at Farnborough was the only focus for this research. It refrained at first from producing official engine designs, and the new Superintendent, Mervyn O'Gorman, did everything in his power to help and encourage the expansion and enthusiasm of private enterprise. An Engine Laboratory was built in order to specify conditions which makers should observe and to apply proper tests to the engines supplied, and in 1911 were built the first engine test stands and whirling arm in which actual flying conditions could be simulated and the performance of an engine measured. This enthusiasm behind the scenes was not always shared outside, as may be gathered from the experiences of Captain Bertram Dixon and Lieutenant E. D. L. Gibbs, both of whom had learnt to fly in France. By arrangement with the War Office they made some reconnaissance flights during the Army manœuvres in the autumn of 1910. These officers had the greatest difficulty in persuading those in command to make use of their services, for the cavalry complained that the noise of the machines frightened their horses. When one of the few reconnaissance flights had to be postponed because of bad weather, scepticism of the value of military aviation was freely expressed, and nowhere more vehemently than in the cavalry.

Meanwhile experiments with army airships were continued without outstanding success. In 1910, the proprietors of the *Morning Post* opened "The National Airship Fund" in order to buy for the use of the nation a semi-rigid airship from the French designers Lebaudy Frères. In the autumn of that year this airship left the factory of the makers at Moissons and reached Farnborough five and a half hours later. The War Office had built a shed specially to house the airship; but, alas, Lebaudy Frères had increased the dimensions of the envelope by more than ten feet without telling anybody about it. When the landing party of guardsmen started to walk the ship into the shed, her envelope fouled the roof and was badly ripped. The shed was raised and the airship rebuilt, but during the next year, when she made her

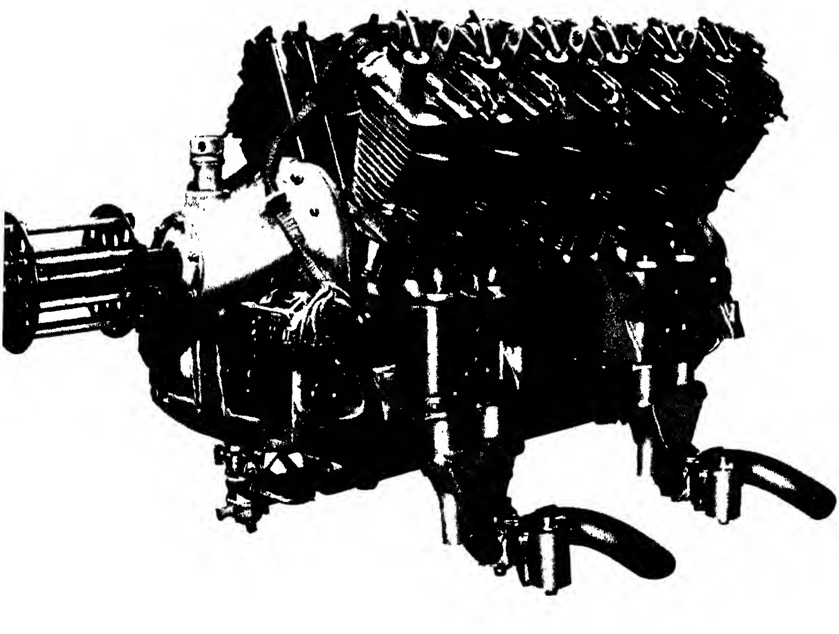


F.E.2B AEROPLANE. This machine was a later development (dating from 1915) of the original F.E. (Farman Experimental) aeroplane of 1910. A considerable number of these aircraft were built and used in the early days of the first world war, and were generally employed as bombers and night-flying aircraft.

S.E.5A AEROPLANE. This machine was the chief fighter (Scout Experimental) aircraft of the first world war; a total of over five thousand of the type were manufactured by industrial firms. The design illustrated above was evolved



ℓ.A.F. 1B and R.A.F. 4C AERO ENGINES. In 1913 the Establishment began to design its own ıero engines. Production was eventually concentrated on these two types. The R.A.F. lb was used in the B.E.2c aircraft, and the R.A.F. 4a—an earlier version of the 4c--in .he R.E.8 aircraft. Many thousands of these engines were built by outside manufacturers.



first voyage, she collided with a house in Farnborough, was wrecked beyond repair, and, according to an elderly gentleman who still recalls the incident, " provided tobacco-pouches for everybody out of pieces of her envelope."

With a war only three years off, the War Office issued an Army Order (dated February 28th, 1911) embodying an Air Battalion " to which will be entrusted the duty of creating a body of expert airmen, organised in such a way as to facilitate the formation of units ready to take the field with troops, and capable of expansion by any Reserve formations which may be formed in the future. In addition, the training and instruction of men in handling kites, balloons and aeroplanes, and other forms of aircraft, will also devolve upon this battalion."

It was soon found that officers joining the new battalion were unanimous in preferring to fly aeroplanes rather than to pilot airships. By the summer of 1911 there were forty applications for vacancies in aeroplanes and none for airships. An aeroplane, that same year, was used for the first time by the Italians for reconnaissance, photography, and bombing, in their campaign in Tripoli against the Turks.

At Farnborough, work on airships came to an end in 1913, when they were transferred to the Admiralty. By the year of the first world war, the Establishment (it was still called the Factory) had a considerable list of achievements to its credit. It had established in the light of existing knowledge the utility and strength of the biplane as compared with the monoplane ; it had designed instruments for recording the tension of wires in flight ; it had designed and made an airspeed indicator and an aneroid ; it had designed and built several new types of aircraft and engines. Certain of these experimental machines had been called " reconstructions " owing to the difficulty in obtaining authority and funds for building new machines. One of them was the first stable aeroplane, a " reconstructed " Blériot machine, the B.E.1. The series names of the other machines were the Farman, Scouting, and Reconnaissance Experimental (F.E., S.E., and R.E.). They were aircraft designed for warfare. Altogether twenty-five different types of aeroplanes and six different types of engines had been designed and tested by 1914.

Farnborough, during these years, was the meeting-place of pilots, designers and scientists, the main source of authoritative statement on all aspects of flying, and the one place in Britain where theory could be tested in the air. By employing on its design side only trained engineers, the Establishment elevated the workers in design and production of aircraft from amateur to professional status.

The Farnborough staff tested aircraft which were submitted to them to a factor of five—that is to say, the structure is capable of withstanding safely five times the loading that it would encounter in normal operations. The concept of the safety factor was not yet understood ;

some of the aircraft designed in those early days could hardly have stood up to the most elementary modern safety tests. Nevertheless, Farnborough standards were considered to be high ; manufacturers whose aircraft failed to pass frequently considered them to be too high.

It would be fitting, perhaps, to close these brief glimpses of Farnborough during the birth of British aviation by quoting once more Sir Walter Raleigh, who, in summing up his own brilliant and exhaustive account, wrote : " It has been a story of small things, of interrupted experiments and tentative advances ; of the caution of the Government, and the boldness of the private adventurer. There is nothing new in the story ; the air was attacked and mastered in the English fashion. When we are confronted with great issues, it is our habit, or so we are fond of saying, to ' muddle through '."

SIX

THE REVOLUTION IN FLIGHT

In speed we hurl ourselves beyond the body.

T. E. LAWRENCE

ONLY then, when the air had been " attacked and mastered," was a new world of possibilities revealed. No sooner had man learnt to go aloft, to remain there, and to fly from one place to another, than innumerable questions arose. How fast and how far could he go ? How many people—or bombs—could he carry ? How would he defend himself, and how attack others ? The first world war, during which the staff at Farnborough increased from hundreds to several thousands, made such questions matter of life or death.

The research people, no longer concerned simply with keeping an aeroplane in the air, were working upon its performance in the air. An illustration of just one line affecting performance lies in the comparison of the Wright brothers' first engine, which weighed 15 lb. for each horse-power it developed, and the Rolls-Royce Merlin II engine, thirty-six years later, which developed over 1,000 h.p. at a height of over 16,000 feet and weighed only 1¼ lb. for each horse-power. Five years later again, the Merlin could deliver over 2,000 h.p. for combat conditions, yet its weight had risen only to 1,890 lb.

These words are being written at a time when every important Power is probably developing jets, and when the fastest aircraft in the world are already flying with these gas-turbine engines. The new power plant in an aircraft may represent a change as significant as that from sail to steam.

For over ten years this plant has been upon the drawing-boards at

Farnborough. And as in the last chapter we observed the emergence of stable aircraft at Farnborough, it may be of interest to follow the idea of the gas turbine from its first appearance at the Establishment in the twenties. If the idea seems on the face of it to represent a break with the ancestral tradition of aeronautics, yet it must be recognised that that tradition of forward-looking and basic curiosity provided the best possible atmosphere for revolutionary progress.

The first practical proposals to use a gas turbine as an aircraft power plant were made in 1926 in Royal Aircraft Establishment Report No. H.1111, entitled " An aerodynamic theory of turbine design". The same year a conference was held at which Dr. A. A. Griffith, who had written the report, put his ideas before a small committee from the Air Ministry and the Aeronautical Research Committee. This conference expressed itself unanimously in favour of the putting in hand of preliminary experiments to verify the theory. Two sets of experiments were started, one on stationary cascades of aerofoils, the other with a small-scale rig to measure efficiencies of the combined turbine and compressor stage.

In 1929, Dr. Griffith proposed a contraflow gas turbine for aircraft, concluding his report with these words: " The turbine is superior to existing service engines and to projected compressor regulated engines in every respect examined. The efficiency is higher and the weight and bulk less. No extraordinary cooling is required. At high altitudes there is an inherent supercharging effect coupled with a substantial decrease in the specific consumption. The use of a variable-pitch airscrew is unnecessary. Starting presents no difficulty and control is simpler than in the case of existing engines. Any liquid fuel of suitable chemical composition may be used without reference to anti-knock value or volatility."

In 1930 a sub-committee of the Aeronautical Research Committee was appointed to consider this and other work on turbines. They reported that "at the present state of knowledge the superiority of the turbine over the reciprocating engine cannot be predicted." They went on to declare that they had no intention of "advocating the large expenditure that would probably be involved in any attempted development of a turbine power plant by the Air Ministry." They recommended that Dr. Griffith's practical experiments should continue, however, and that experiments on the rapid combustion of fuel at constant pressure be made, as data of this type would have a wide field of application.

These recommendations, however, were not carried out; no further work was done at Farnborough on the gas-turbine engine until 1937, although work continued on centrifugal superchargers and exhaust turbines. Many years of work had already been spent on the development of exhaust turbo-superchargers, flight tests having been made with

them fitted to a Napier Lion engine between 1926 and 1929, and again in 1934. A long series of mechanical failures, chiefly in bearings and blades, convinced many that the prospects of success with the materials then available were slight. Improved materials and the means of installing and cooling the bearings were finally found, too late ; but the knowledge of them was available to assist later in the development of the gas turbines.

Revival of interest in the gas turbine scheme came in April 1937, when the Establishment asked for authority to build an axial-flow supercharger. The first axial-flow compressor, christened with the becoming code-name *Anne*, was completed in 1939, but, owing to over-heating, stripped its blading thirty seconds after starting. *Anne* ultimately was one of the few casualties when a German bomb fell at Farnborough in August 1940, but the results of her tests were promising.

In 1937 a most significant report emanated from the Establishment, written by H. Constant, and again asking for authority to build, stressing the ultimate value of the internal combustion turbine in these words :

> "In the light of existing knowledge, an internal combustion turbine could be constructed using only types of components which have been proved by past experience. The performance of such a turbine, on the basis of specific weight and economy, would be better than, or substantially equal to, that of the best modern water-cooled petrol engine, except when cruising at comparatively low altitudes.
>
> Under take-off conditions, both its specific weight and specific fuel consumption would be less than that of the petrol engine. At an altitude of some 20,000 feet, its specific weight and specific consumption would be similar to that of a petrol engine operating under economical cruising conditions. Below this altitude, its specific consumption would be greater and its specific weight less than that of the petrol engine.
>
> Possible developments in materials and air compressor design foreshadowed by recent research suggest the possibility of constructing in the near future an internal combustion turbine whose specific weight would be less than that of any internal combustion engine at present in production under all conditions of flight and whose specific fuel consumption would be less than that of any compression ignition engine, under all conditions of flight.
>
> The simplicity of the internal combustion turbine, with its freedom from the inherent complications of the reciprocating engine, has made it the dream of many engineers. The very magnitude of the advantages which it has to offer, associated with the repeated failures to achieve a practicable design, have given the impression that the internal combustion turbine is merely a convenient medium on which to work off the surplus energy of imaginative inventors. In fact, however, the same principles and the same practical experience as have in the past predicted the performance of machines of far more novel design can be applied to determine the probable success or failure of the internal combustion turbine."

The Aeronautical Research Committee declared itself vigorously in favour of a turbine airscrew scheme and of Group Captain Whittle's scheme, which until then had received no financial or advisory help from the Air Ministry. In their report of May 1937, the Engine Sub-committee of the Aeronautical Research Committee recommended "that the Air Ministry should take up the question of the development of the internal combustion turbine as a matter of urgency and make all possible arrangements for its production at the earliest possible moment. They consider that this will probably require the co-operation of turbine builders and recommend that the possibilities in this direction should be explored without delay."

On April 13th of that year, the Royal Aircraft Establishment's Drawing Office received instructions to start work on a gas turbine engine, and representatives from Farnborough soon afterwards visited Messrs. Metropolitan-Vickers Ltd. to discuss plans for joint research and development. It was agreed that work should go forward with all speed on a low-pressure axial compressor driven by a low-pressure turbine in series with a high-pressure axial compressor driven by a high-pressure turbine. The plant was begun in 1939 and most of its mechanical features proved satisfactory.

During the late thirties, many schemes were suggested and examined. They were all worked out with various industrial firms in conditions of secrecy. From the start the aim of the Establishment had been to develop an engine which would beat conventional types on both fuel consumption and weight. Group Captain Whittle and Power Jets Ltd. had been concentrating on a much simpler jet-propulsion turbine suitable primarily for high-speed, high-altitude aircraft. In September 1939 the Establishment suggested to Power Jets Ltd. the use of an axial compressor in a jet-propulsion turbine and a design known as the F.1 was produced. Unfortunately, Power Jets were compelled to abandon the project owing to pressure of other work. Metropolitan-Vickers agreed to take it over. Accordingly the F.2 design went to this firm.

Manufacture started in December 1940, and the first unit was completed in November 1941. No aircraft had been designed for the use of this engine, and there was some delay before a Meteor prototype could be adapted to take two F.2 engines. The engine, however, was first airborne in what was known as a Lancaster test bed in 1943. This test bed was contrived by fitting the new engine unit into the tail gun-turret position of the Lancaster. The engines were fitted and flown in a Meteor for the first time from Farnborough in November 1943.

As between Group Captain Whittle's organisation and Farnborough, the development of turbine engines was parallel, Whittle developing the centrifugal type and Farnborough working mainly in

the first instance on the axial type. Both types were flight-tested at Farnborough in 1943, and a large staff worked on the many development details involved in the new methods of propulsion. Both of these types are now adopted by industry.

At the end of the war, the Government, in order to rationalise the research and development of the gas turbine, created a new body known as the National Gas Turbine Establishment, which is manned by the majority of the original research workers from Farnborough and by the staff of Power Jets Ltd. This establishment is at Pystock, separated from the Farnborough Establishment only by the airfield which is their common testing ground.

The coming of jet propulsion brought with it the promise of spectacular speeds in the air. The R.A.F. record-breaking Meteor was tested at Farnborough before the record was attempted in the summer of 1946, when research workers from Farnborough acted as timekeepers. The new speeds attainable confronted the various specialists with problems of great significance, particularly in aerodynamics and in aircraft structure, and gave even more exacting and dangerous tasks to the test pilots.

Jet propulsion has brought mankind face to face with the sonic barrier. When he flies at the speed of sound (760 miles per hour) he reaches a point where the air ahead can receive no warning of the impending passage of his machine. A reasonable amount is known about what happens beyond this point, but at the time of writing elaborate experiments have been going on for years concerning the behaviour of the aircraft at the moment of reaching the barrier. The situation has been tackled not only by means of placing models in wind tunnels which simulate the conditions of aircraft approaching sonic flight, but also by test flights by pilots belonging to the Experimental Flying Section at Farnborough, who have deliberately undertaken dives approaching the danger-point.

In 1944, for example, Squadron-Leader A. F. Martindale, A.F.C., carried out high-speed investigations. He took a Spitfire from 40,000 feet into a high-speed dive in which he attained over 90 per cent. of the speed of sound. In attaining this speed, sudden changes of trim of the aeroplane were experienced, as anticipated, and he was only able to keep on his course by holding the control column in both hands. Such a dive as this necessitates most accurate flying and the very calm appreciation of what is happening at the time in order to prevent acceleration which might cause structural failure.

Martindale continued his experiments. On one occasion in the same year he was diving when the wooden propeller and reduction gear were torn out of his aircraft. By superb airmanship, he brought the machine back to base, together with the recording instruments, so providing extremely useful data for supersonic research.

Another aircraft was obtained, fitted with a metal propeller, for the completion of the work, and in it, a few months later, Martindale dived from 36,000 feet. The engine over-speeded when he was at 24,000 feet, the supercharger burst, and the aircraft caught fire. Realising that he was over the western outskirts of London, Martindale stayed in the aircraft and headed for open country. The fire died down, so he decided to attempt to make base, although flames were still coming from the aircraft. On approaching, he found the airfield obscured by cloud, so decided to force-land and made an approach to a field near Woking. His windscreen being covered with oil, he did not notice that high-tension lines ran directly across his approach until he was almost upon them. He had no alternative but to crash in a wood. The aircraft burst into flames, but he got clear. When he had taken off his parachute, and although he was injured in the spine, he found his way back to the flaming aircraft and retrieved the recording cameras, which contained valuable data about his flight. After this he managed to keep onlookers clear of the wreck until the local fire brigade arrived.

Not the least of the fresh dangers with which airmen are faced at high speed is that of escaping from the aircraft if there is a failure. It is known that at high speeds clothing, and indeed limbs, may be torn off if suddenly exposed to the airstream. If the airman is to escape, he must be exposed simultaneously, and for that reason Farnborough has been concerned with the development of a pilot seat which in a fraction of a second ejects a man from his cockpit. The need for some sort of artificial ejection is demonstrated by the experience of the late Squadron-Leader W. D. B. Davie of the Experimental Section, who in 1943 was forced to abandon his aircraft at 36,000 feet. The speed at which he left the aircraft was such that his oxygen mask was torn off, rendering his emergency oxygen supply ineffective, and also such that he had to allow himself to fall freely in order to lose speed before he opened his parachute. While falling, he felt for the broken tube of his oxygen supply and put it into his mouth, thus providing himself with sufficient oxygen to enable him to retain consciousness and operate his parachute successfully. He saved his own life and was able to bring back a complete and most valuable report of the reason for the aircraft's failure.

Hundreds of deeds such as these have contributed to the knowledge of jet propulsion and to the approach which is being made to flight beyond the speed of sound. Theory and practice have been closely interwoven to provide the pattern of this progress. As in the days of the Wright brothers, Capper, Cody, de Havilland and Rolls, a skilful interplay of thought and action is mastering the unknown elements of aviation.

SEVEN

THE HARVEST OF ONE WAR

Should the point be carried, and man at last become as familiar with the air as he has long been with the ocean, will it in its consequences prove a mercy, or a judgment? I think a judgment.

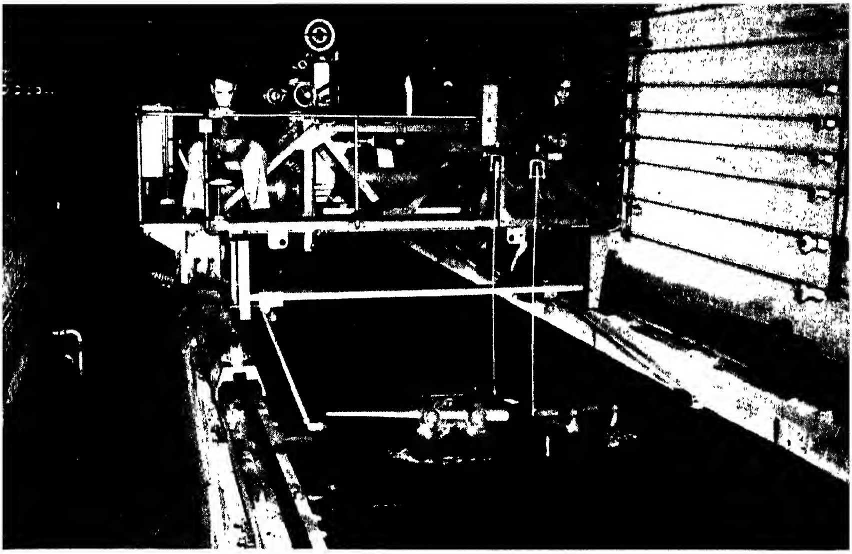
HORACE WALPOLE

FLIGHT is no longer an adventure, but an acknowledged means of locomotion, considered by some to be less risky than motoring in Britain on a Bank Holiday. Those who seek adventure in the air in times of peace do so dispassionately in order to enhance knowledge of a still mysterious element.

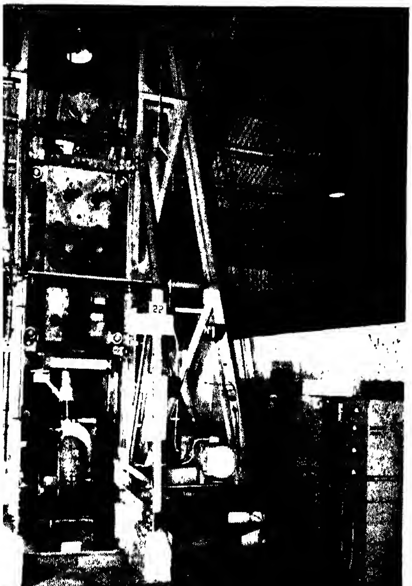
A list of those who have died in the cause of aviation at Farnborough would be impressive not in numbers alone, but also by reason of the talent and objective courage with which the experimenters were endowed. There have been times when their spirit of inquiry was particularly fruitful, and when resources were abundant for the scientists and research workers who collaborated with them to further their common cause. At other times, that cause suffered from neglect, restriction, or active opposition.

It was, in fact, after many long years of work—often dangerous but carried out with an enthusiasm never damped by opposition, scepticism, and restraint—that the Establishment emerged with a clear purpose in the period before the world war. Its functions had resolved themselves into the design, testing and experimental work on aeroplanes, engines and accessories ; the repair of aeroplanes and engines ; and the buying and issuing of stores.

When the Royal Flying Corps was constituted in the spring of 1912. the Establishment had been incorporated into the new service with the title of Royal Aircraft Factory (a title dropped later because its initials were identical with those of the Royal Air Force). The imminence of the first world war, and a rather sudden emphasis of Government policy on heavier-than-air machines, followed a period of neglect and of the more or less haphazard purchase of foreign engines, and found the country desperately short of skilled manufacturing capacity. For this reason, more than any other, Farnborough received its first substantial prototype production order—the manufacture of twenty-four aeroplanes of the R.E.5 type. When war broke out and until 1916, therefore, the Establishment had for the first and only time a four-fold function, combining the main supply of aeronautical information with the carrying out of official tests, with design, and with

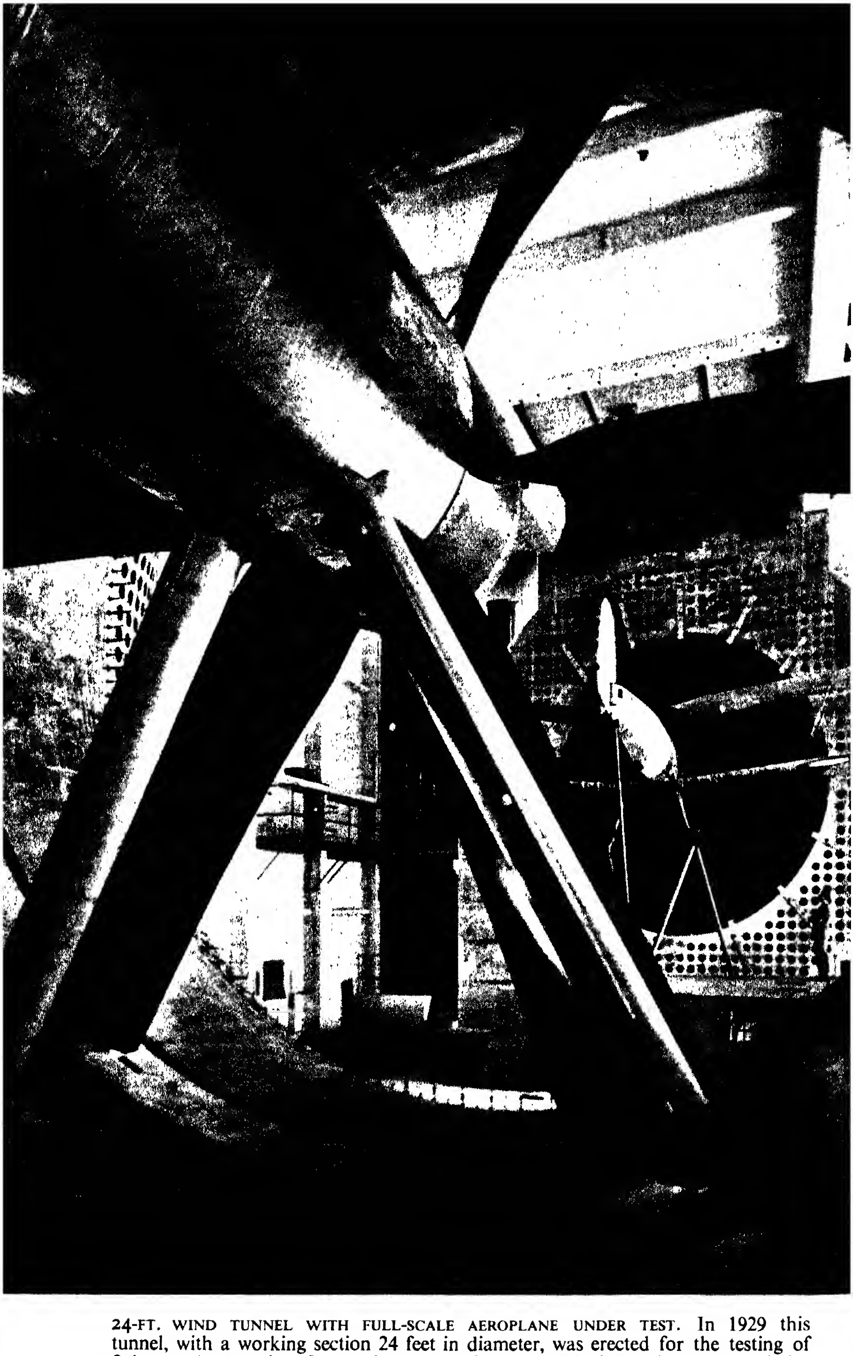


MODEL FLYING-BOAT IN SEAPLANE TESTING TANK. A tank 660 feet in length, having a carriage speed of 40 feet per second, has been in operation for the past 15 years for testing the water characteristics of seaplane floats and flying-boat hulls. This model is equipped with miniature air turbine motors to provide slipstream effects.

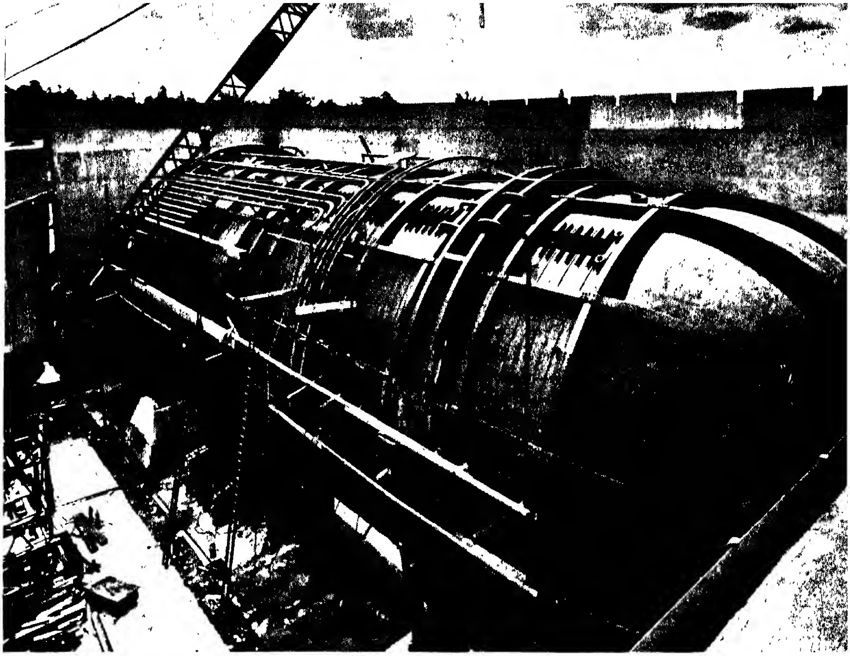


UNDERCARRIAGE DROP TEST MACHINE. Full-scale analytical methods are used to investigate the actual strength under full load of important auxiliaries of the main aircraft structure, such as undercarriages and tail wheels. Most operational conditions of loading can be simulated.

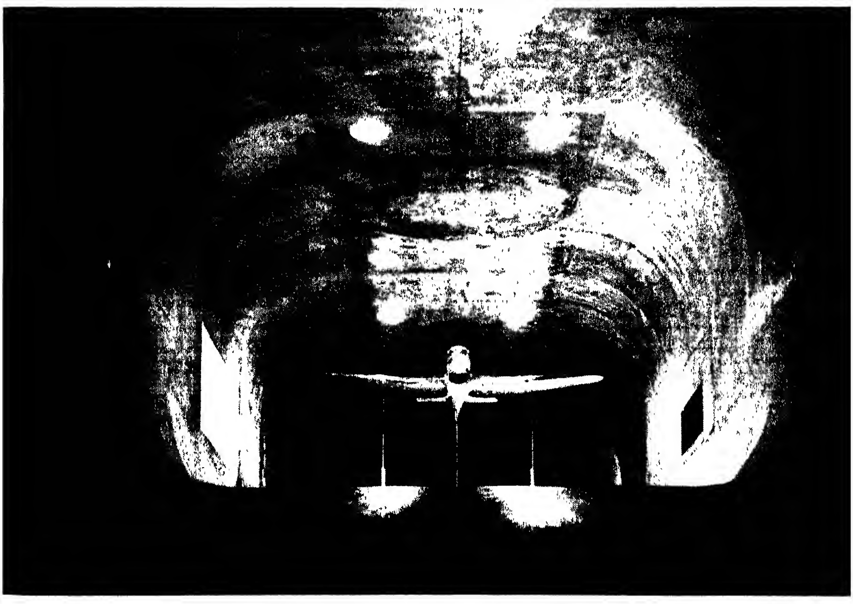
ENGINE TEST CHAMBER FOR COLD STARTING. The problem of getting fighter squadrons into action quickly in very cold climates was analysed under actual simulated conditions. A dependable technique was developed for starting aero engines quickly and simply in temperatures of $-20°$ C. and below.



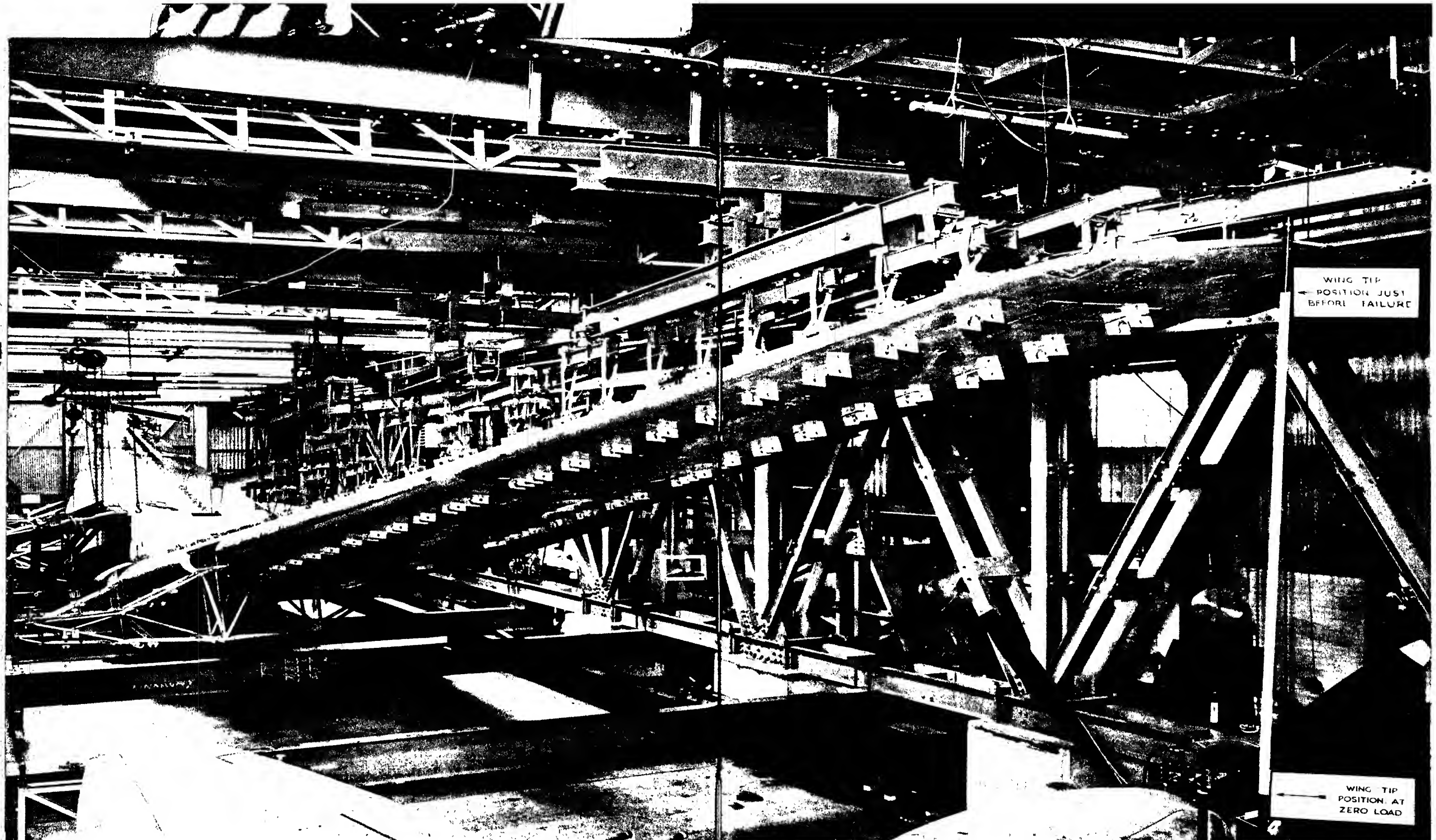
24-FT. WIND TUNNEL WITH FULL-SCALE AEROPLANE UNDER TEST. In 1929 this tunnel, with a working section 24 feet in diameter, was erected for the testing of fighter and other aircraft. During the war it was used in full-scale aerodynamic investigation of bomber power plant units and of such other features as air flow through air intakes and engine radiator orifices. This view is taken through the collector ring.



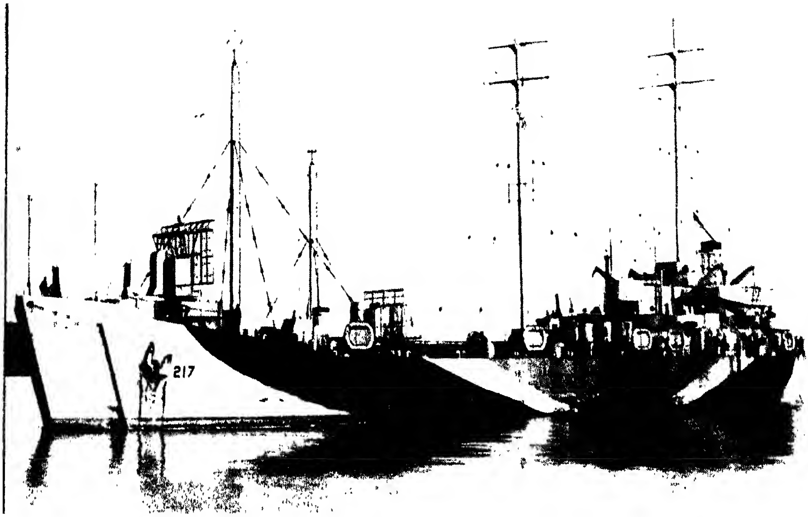
HIGH-SPEED WIND TUNNEL DURING CONSTRUCTION. The substantial increase in aircraft speeds ten years ago necessitated the provision of better equipment for accurate aerodynamic tests at high speeds. This tunnel, constructed during the war, is capable of testing 6-ft. span scale models at air speeds of over 600 miles per hour.



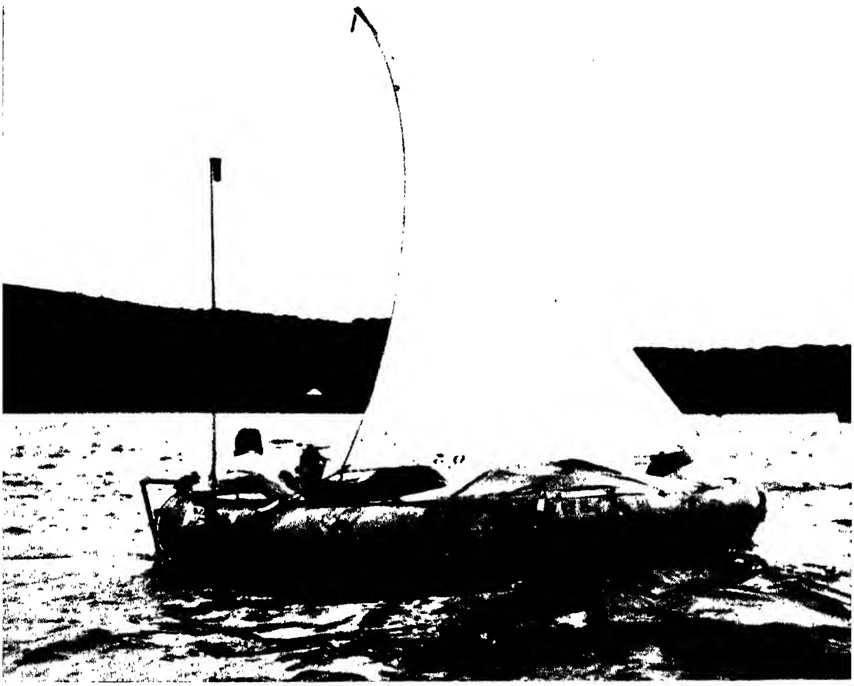
MODEL OF TYPHOON FIGHTER UNDER TEST IN HIGH-SPEED TUNNEL. Here a scale model is shown in position in the working section of the high-speed tunnel.



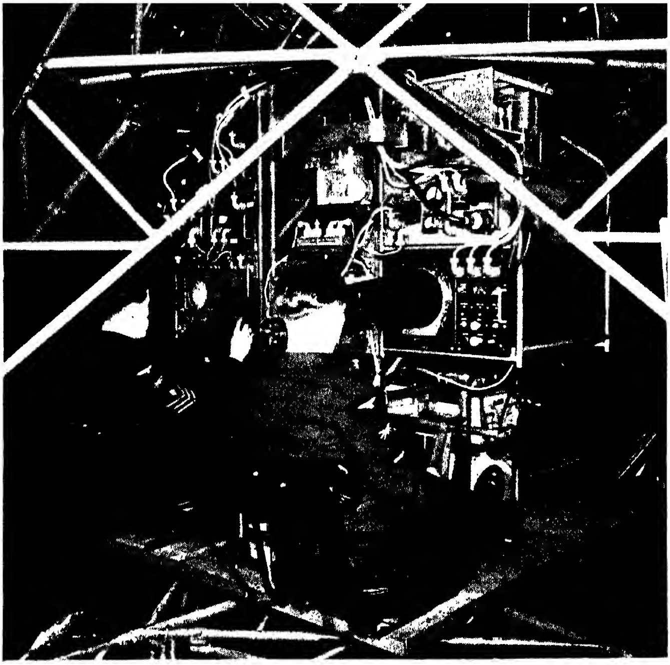
LINCOLN WING BEING TESTED TO DESTRUCTION IN STRUCTURE TEST FRAME. This method, used in conjunction with a flexible and sensitive electrical strain gauge recording technique, provides accurate strength analyses of aircraft wings and structures to destruction point. Discovery of the weak points in any design enables its eventual load capacity and factors of safety to be very considerably improved.

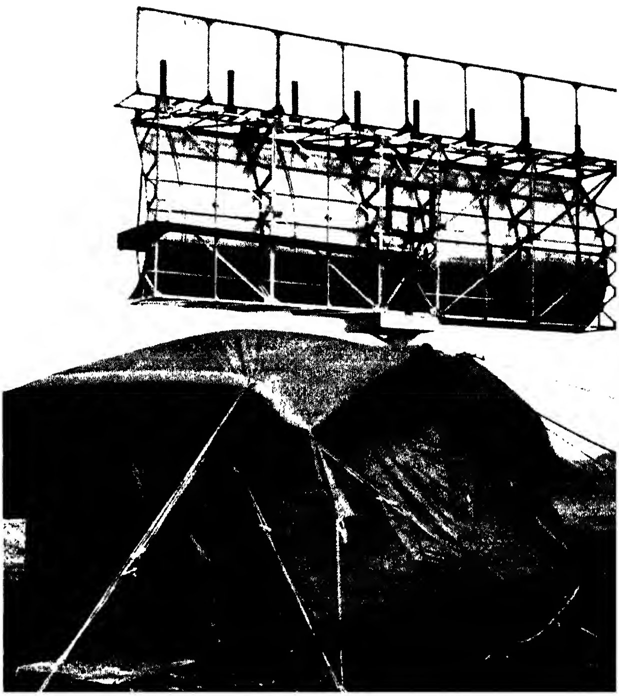


FIGHTER DIRECTION SHIP. These vessels were designed to provide fighter control and radar facilities during landing operations such as those of the invasions of Sicily and Normandy. In conjunction with the R.A.F. the Establishment carried out a great deal of work in connection with radar and radio communication.

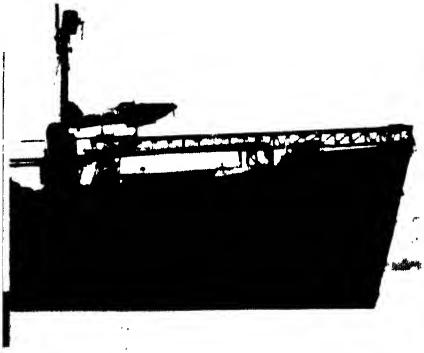


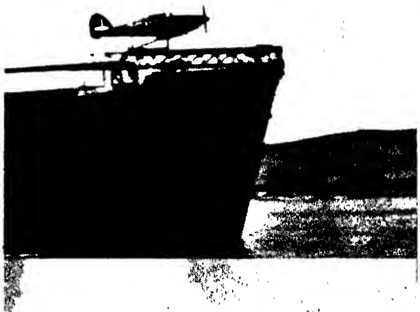
SAILING DINGHY FOR AIR CREW RESCUE. Much work was done at Farnborough in the evolution of equipment responsible for the saving of a great many lives of air crews during the war. The example shown is a completely-equipped sailing dinghy which can be contained in a small space and quickly inflated in any emergency.





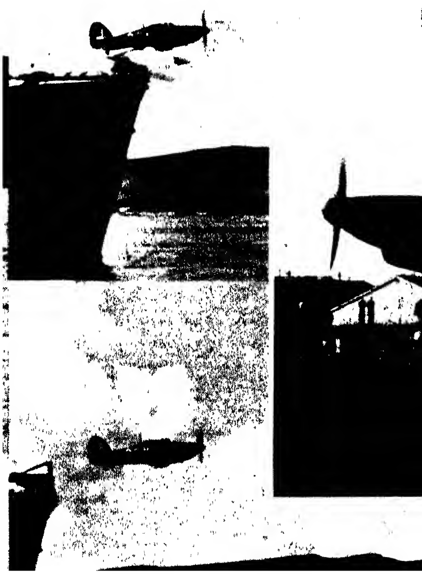
IO CM. RADAR GROUND STATION. This unit was intended primarily for use in the Far Eastern operations. The equipment, largely developed at Farnborough, was built in a form which could be subdivided for transportation by air.





CATAPULT AND ROCKET TAKE-OFF TESTS. Nearly 20 years of research and experiment have gone to the evolution of the catapult take-off system extensively used for launching ship-borne aircraft during the war. This work is done in close collaboration with the Admiralty.

Left: a Sea Hurricane aircraft catapulted from a ship. *Above:* rocket-assisted take-off from ground. *Below:* rocket catapult take-off: both at Farnborough airfield.



manufacture of prototype aeroplanes, subsequent manufacture being left to industrial organisations. (The only occasion upon which production proper was undertaken was in 1917 and 1918, when about 240 S.E.5's were produced because a sub-contracting firm was in difficulties.) By June 1915 the area of the shops had been increased more than ten times, while staff which had numbered 100 in 1909, and 1,250 at the outbreak of war, had reached the figure of 5,000 (in the second world war its peak figure was 6,500).

It was fortunate that this expansion of effort was controlled by such a personality as that of Lieut.-Colonel Mervyn O'Gorman, whose understanding and flair for direction were in the first instance recognised and encouraged by Mr. Haldane. O'Gorman surrounded himself with brilliant men such as F. M. Green, F. A. Short, S. Keith-Lucas, E. T. Busk, G. I. Taylor and G. P. Thomson ; and the experimental staff was increased to about 1,000.

In the records appear eminent names, such as that of Professor F. A. Lindemann, now Lord Cherwell, who by his researches and courageous experiments proved that any aeroplane can spin, and that a pilot who understands the principles of a spin can recover from it when there is height to spare. These particular tests were made as part of a series of aerodynamic experiments which have now become classic. Based on work by Dr. G. H. Bryan, these experiments followed a strong demand for an aeroplane which would be inherently stable in flight. The demand was greatly accentuated by many deaths of pilots apparently attributable to lack of inherent stability in their machines.

Geoffrey (afterwards Sir Geoffrey) de Havilland, designer and test pilot at the Establishment during this period, was, in conjunction with F. M. Green, its first designer of complete aeroplanes, the S.E.1, and later of the better-known B.E.1.

His designs were the first to be produced by the co-ordination of model and full-scale experiments linked by mathematical investigations. The first general-purpose machine, the B.E.2, a development of the B.E.1, was the fruit of research work in inherent stability by E. T. Busk, who met his death in November 1914.

In 1914 was designed and produced the famous S.E.4, which achieved the then unofficial world's record with a maximum speed of 131 m.p.h. Next was produced the F.E.4, twin-engine 3-seater biplane bomber. Besides the design of complete machines, very wide research in aerodynamics, armament, photography and wireless was carried out during these first war years at Farnborough. Pressure of work became so great that on August 6th, 1915, after running incessantly every day and night for twelve months, the factory was closed for three days in order to permit the employees to rest.

Mainly because of its new function of design and prototype manufacture, the Establishment came in for strong criticism during these

first world war years, though the figures show us that 533 aircraft of thirty-three different types were built between 1911 and 1918, which amounts to not more than sixteen of any one type. Pemberton Billing, M.P. for East Herts, maintained that State-controlled industry, in particular the Royal Aircraft Factory, was inefficient as compared with private enterprise. He alleged that " the officials who were responsible for deciding types of machines . . . failed either by ignorance, intrigue or incompetence to provide the best machines that this country could produce." At a Judicial Inquiry conducted by Mr. Justice Bailhache into the administration and command of the Royal Flying Corps, another Member of Parliament, Captain Bennett Goldney, giving evidence, stated that " The Royal Aircraft Factory was no longer a school of research and experiment, but a large main factory, competing unfairly with private enterprise, with which an attempt was made to create a virtual monopoly." Such was also the main burden of criticism in a section of the Press.

As the result of such criticisms specifically directed against the Establishment, a separate investigation was made into the affairs of Farnborough. In its findings this committee, under the chairmanship of Sir Richard Burbidge, recommended a stricter observance of the original terms of reference of the Establishment, namely, that it should foster aeronautical research and development rather than engage in production, even of experimental prototypes. The committee considered Farnborough to be an experimental laboratory where expense must necessarily be high, and that it could not be run on commercial lines. The specific charges which had been made regarding errors in drawing were found not to be substantiated. It appeared that designs prepared at Farnborough for the production by hand of prototype aircraft were handed over to industrial concerns for manufacture without having been re-designed for production. The factory staff was capable of re-designing them and would, in fact, have done so if the urgency had not been so great.

Though the Burbidge Report did not recommend discontinuation of the designing of aircraft, the decision to discontinue was apparently taken very shortly after the issue of the report. Design work actually in hand at that time was completed, but no new projects were undertaken. Manufacture of aircraft was not, however, regarded as having been finally given up. Plans were made during 1918 for the manufacture of Handley-Page bombers, the " Bomb Berlin " aircraft, although the end of hostilities caused this project to be abandoned.

The limitations imposed upon the work at Farnborough detracted little from the essential value of the organisation. The late Sir Sefton Brancker, speaking of this first war period, said : " Practically all aircraft designers, although some of them may have bitterly opposed the policy followed in connection with the Royal Aircraft Factory, admit

that they owe much to the high standard set and the information distributed by this Government establishment.''

Of very great value was the comprehensive nature of the responsibility laid upon the Establishment, which included the creation of some order out of the chaos surrounding the birth of aviation, and the origination of scientific methods of coping with its problems. When a prototype aircraft was flown for the first time from the airfield, its success was due, to a much greater extent than could now be the case, to the men who were present to watch it. They had no great body of aerodynamic knowledge on which to draw. Advance on previous types was largely based on their own research. This advance was often considerable, particularly in the early days. In addition to contributing to the basic research upon which the aircraft design was founded, the scientists and engineers at Farnborough had undertaken the design itself. They had constructed every significant part of the air-frame and engines in their own workshops ; they had re-designed and built their own instruments and equipment. Even the pilots who flew the aircraft had, in those days, acquired much of their skill over the Farnborough Common airfield. Those who were there before and during the first world war rightly claim that this comprehensive responsibility was a powerful stimulus effective far beyond the confines of the Establishment.

All who then worked at Farnborough were conscious of their share in a new departure of science and engineering. The creation of new aircraft was a task for enthusiasts, at least until 1916. At Farnborough was constituted the greatest single repository of aeronautical knowledge in the country.

EIGHT

MANY BIRDS OF GOOD WING

Certainly many birds of good wing would bear up a good weight as they fly: and spreading feathers thin and close, and in great breadth, will likewise bear up a great weight, being even laid, without tilting at the sides. The farther extension of this experiment might be thought upon. FRANCIS BACON

IT is no secret that the years between the wars were among the most difficult ever experienced by British aviation. Economy strictures were applied not only to the Royal Air Force as a whole, but also to such units as the Royal Aircraft Establishment. Only enthusiasm which

could not be more than damped, and wisdom patient and far-seeing, ensured the existence of that nucleus of airmen whose daring and efficiency in flight in the second world war was the wonder of the world.

The number of employees at Farnborough in November 1918 was 5,052 ; by June 1920 it had been reduced to 1,380. In the following years Farnborough absorbed the Instrument Design Establishment from Biggin Hill and the Airworthiness and Contracts Technical Supervisory Department of the Air Ministry. In 1924 a committee under the chairmanship of Air Commodore F. C. Halahan, D.S.O., was set up to examine the organisation of the Royal Aircraft Establishment and to report what steps, if any, should be taken to reduce its cost without impairing its experimental value as an establishment in peacetime or its capacity to extend in an emergency. This Committee stated that the function of the Establishment should be to provide a full-scale aeronautical laboratory for the Air Ministry. Its main tasks would be development work on experimental aeroplanes and engines, testing of experimental instruments, development of special flying instruments for which little commercial demand existed, and investigation of failures. To this work was added that of liaison with contractors, research, technical supervision, the construction of experimental machines, and the stressing of new types of machine. These terms of reference have remained substantially unchanged to the present day, though from time to time they have been rather widely interpreted. The Establishment has often had to answer urgent calls for advice or for research action, and has often been found the only repository for certain kinds of vital aeronautical knowledge. The organisation has exhibited a typically British characteristic ; appearing sometimes to work out its destiny in haphazard fashion, it has in fact always been capable of rising to any emergency at short notice. Moreover, the staff has always seemed to revel in diversity. A random selection of more or less recent interests would range over such an assortment as proximity fuses, electrical heating of clothing for air crew, jet landings on aircraft-carriers, de-icing gear for the King's Viking, automatic landing gear for civil aviation, radio traffic control, and how to keep physically cool at 1,000 m.p.h.

Many functions of the Establishment have been assumed almost subconsciously ; it is difficult to draw exact frontiers between its work and the work of the Services and aircraft industry. Lacking space in these pages to do justice to all the activities focused within this strange, sprawling laboratory alongside the airfield, let us glance at the departmental work which a visitor might find in one or two of the basic theatres of action. It may be proper at this stage to pass on the warning sometimes given to laymen visiting Farnborough : " We have had technically-minded Air Marshals coming here to see the wheels

go round who tell us after a few hours that they have mental indigestion." It must be confessed that there is in the laboratories a concentration of thought and research formidable to the non-specialist: this survey is intended as an indication to him of the quality and background of the work of the Establishment rather than as an attempt to give the student details which cannot be adequately compressed. It should, above all, be recognised that continuity is one of the many virtues of the place ; shrinkage of facilities between the two wars left that virtue whole. Resilient and flexible, the organisation is still able to probe every aspect of aeronautics which may appear in the partly unexplored region beyond speed of sound.

It would be invidious to place the departments at Farnborough in any order of precedence, but the visitor can hardly fail to be impressed first by the two applications of science probably most fundamental for aviation, namely, aerodynamics and aircraft structure.

Since Colonel Capper's time, when students of aerodynamics placed the models of airships in water in order to ascertain the behaviour of their shapes, the aerodynamic department has worked upon the problems of how bodies shape to the air. From 1907, when the first wind tunnel was built, tunnels of ever-increasing power and accuracy have been thought out and made by this department. Its members' job may be briefly defined as provision of aerodynamic information needed for current problems and projects in aircraft, exploitation of advances in theory and their co-ordination with flight experience, indication of the most profitable lines of advance in aircraft design, and employment of their experimental resources in solving urgent problems arising in the use of aircraft and in tests of specific prototypes in order to assist the aircraft industry in matter of design. For example, in 1924 the department was interested, among other things, in the control of aeroplanes in flight beyond the stalling angle and the combination of slot and aileron control for this purpose. In 1943 it was investigating night-towing schemes for gliders. At the time of writing a model of a Tudor civil aircraft is being checked over prior to the introduction of this type into service.

The models used are pleasing to the heart of the schoolboy which is hidden in every one of us. They are built to scale, sometimes in steel but mainly in wood—teak, mahogany, or yellow pine—in the joiners' shop, and they have a rich, dark, shining finish such as one expects in the very best furniture. Highly-skilled craftsmen make them by hand. They are, indeed, the product of another tradition which has not perhaps received due attention in this narrative. G. Parfett, who is at present in charge of the wood section, was in 1912 employed in making the wooden propellers of the B.E.1 machine. The high degree of skill of his woodworkers, who make models of the most up-to-date jet aircraft, has grown out of the very exacting and specialised task of

shaping propellers with an adze. Their exquisitely-finished, toy-like structures are the basis of most of the work on aerodynamics.

When the plan of an aircraft is first conceived, estimates are made of its performance and its stability and its control characteristics. Following these paper estimates, a model is usually made. The models vary in scale : they may be as much as a third of the size of the projected aircraft, or they may be scaled down to a replica of inches to be used in the modern high-speed wind tunnels. Tests in the wind tunnels may indicate necessary modifications of design. After tests, for example, tailplane size or fin size may be altered ; the modification is embodied in the detailed design which the manufacturers use in making the first prototype aircraft, which ultimately emerges for its flight trials. During the trials there is close liaison between the Establishment and the manufacturers, since many " teething troubles " are likely to appear which can be theoretically investigated on the spot. Aerodynamic experts, in fact, maintain their study of the new design throughout the early part of its life. Any peculiar behaviour in the air may result in fresh aerodynamic tests being carried out on the model in the wind tunnel ; the complex and very thorough data which a modern wind tunnel procures often give a quick answer to questions raised by air tests. Only when the aircraft has been flying long enough to approach obsolescence does expert interest fade, and even then the value of the aerodynamic work is not lost, since its history will be applied to future designs.

During the war there was a constant struggle between the aerodynamic experts, the British at Farnborough, and the Germans in such centres as Adlershof and Volkenrode, to outmatch each other's achievements in the increase of manœuvrability, so important in both fighters and bombers. During the autumn of 1942, for instance, the bulk of our fighter force consisted of Spitfire Vs, with a sprinkling of Spitfire IXs and Typhoons. The enemy had gained temporary superiority in speed with the F.W. 190 ; it was, of course, essential to overtake them again if our fighter force was not to be outmanœuvred. The Farnborough Establishment was called upon to devise methods of improving the top speed of the Spitfire V.

A flight programme was put in hand, and from it the aerodynamics staff demonstrated that an increase of 30 m.p.h. in top speed could be obtained by carefully painting and finishing the whole aircraft, by modifying the exhausts, and by removing or fairing* some of the external equipment. Nine miles per hour was, in fact, gained by improved surface finish, and the R.A.F. introduced a special trade into the Service for the maintenance of such a finish upon operational Spitfires.

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* *Fairing* is the procedure adopted to blend external excrescences on an aerodynamic structure in order to minimise resistance to the air flow over it.

Two years later the appearance of the Flying Bomb again made it imperative to get every ounce of performance out of our fighters. Performance tests at Farnborough resulted in modifications which gave the Mustang an extra 23 m.p.h. in top speed. Gains of 8 m.p.h. were obtained for the Spitfire XIV by " cleaning up " the general finish through aerodynamic study.

To study the effects of flight approaching the sonic barrier, a 4,000 h.p. high-speed wind tunnel has been built for the Aerodynamics Department ; in this tunnel it is possible to test models of some 6-ft. wing-span at speeds up to 600 m.p.h., and smaller models at over 0·9 of the speed of sound, i.e. nearly 700 m.p.h. The tunnel is totally enclosed in a large steel shell in which the pressure can be varied from one-tenth to four times the normal atmospheric pressure. The model under test is mounted on a balance which automatically measures the lift, drag and side forces, as well as pitching, yawing and rolling moments. All recent very high-speed designs have been tested in this tunnel. The results of such tests are checked in flight by the Experimental Flying Unit, whose pilots may take the aircraft up to 40,000 feet in order to obtain high-speed dives.

Of equal importance with aerodynamics to the flight of an aircraft is the strength and rigidity of its structure. This was one of the early preoccupations at Farnborough, and a visitor can still see a model of an early biplane covered with small bags of lead weights. The primitive and rather rough-and-ready method of testing the strength of wings was to add bag after bag of lead shot to them, to see how much they would stand ; and it was in fact the origin of the factor-of-safety method of stressing. In recent times, the Structure Department have been conducting important investigations of flutter and vibration. That good, clean, English word *flutter* exactly describes the condition of an aeroplane excited by energy that is being drawn from the air. It is an unstable situation which might be compared with the humble wheel-wobble in an elderly motor-car set up by a bump in the road at a certain speed. Similarly, internal vibrations occur within the actual structure of an aircraft.

All gusts encountered in the air cause stresses upon the structure ; it is the aim of the Structure Department to be able to tell manufacturers how strong and stiff every part of an aeroplane really is, both statically and dynamically. By such knowledge faults can be rectified and accidents avoided.

At an early stage, therefore, in the design of any new aircraft, discussions are held with the manufacturers to decide what structural tests are to be carried out at Farnborough. These tests have changed with the years from loading with lead weights to dramatic large-scale experiments. Specimens of a whole wing, fuselage, or tailplane are sent to the department to be placed in specially built test frames and

rigs. There they are tested to the point of destruction. Before the world speed record attempts, for example, all the units of a Meteor went through such a series of tests. The wing of a Lincoln bomber under test was bent like a drawn bow, the tip of it moving eight feet before it snapped.

Intricate devices constantly record the stress in every part of the structure while these tests are going on. The surface of the subject under test is flood-lit, and cameras record the gradual wrinkling and the showing-up of the weak points before destruction. This work is not without its exciting moments as the specimen shows signs of severe strain, while the designers anxiously wonder whether it will justify their calculations.

Strength tests of the wing of a Mosquito gave an illustration of the value of this work. Several tests were made, and after each the specimen was repaired and improved. The final test achieved a 40 per cent. higher breaking load than the first. Applied to heavy bombers, the work of this department enabled the all-up weight of a Lancaster to be increased from 60,000 lb. to over 70,000 lb. Tests of behaviour under load are also of great importance in working out designs for under-carriages, propellers, and fuel tanks, as well as for the main members of the aircraft.

In the days of Cody, a great deal of experimentation was of necessity carried out in the air. Ground tests for such equipment as propellers might indeed be made—as older members of the staff recall—by placing several model propellers in succession to spin on a lathe and by holding a nut on the end of a string in front of each of them to see which was the most effective in blowing the nut out of the perpendicular. But the emphasis then was upon experience in the air ; and in these days, while research and experiment on the ground may be infinitely more comprehensive, it is always continued in the air at an early stage. There has always been an ample supply of aircraft of many types for use as flying laboratories. Facilities have been created to enable scientists to familiarise themselves with the air. W. S. Farren, Director of the Establishment during the war years, began flying at Farnborough in 1915, and continues to fly such aircraft as Spitfires, in spite of the fact that he is on the mature side of fifty. He encouraged the Flying School in which many Farnborough theorists have become pilots as familiar with conditions in the air as they are with their own benches in the laboratory.

The internal organisation of the Royal Aircraft Establishment has been determined by the multiplicity of its problems. Most of these problems, whether of research or of development, fall into two classes ; the departmental system has been designed to meet them. Central workshops cater for all departments, operating in a system of planned priorities. The fitters, instrument makers, coppersmiths, millwrights

and founders of these workshops constitute a body of skilled labour which it would be difficult to equal anywhere. Some of these men, engaged as boys in making the parts for Queen Victoria's balloons, have lived to make the parts for the special bomb-sights used in the aircraft which destroyed the Möhne Dam. Many of them have sons, and even grandsons, who have followed them to Farnborough as apprentices, and are even now receiving an almost unique training in the skilled trades which contribute to the success of aviation.

NINE

THE HEAVENS FILL WITH SHOUTING

For I dipt into the future, far as human eye could see,
Saw the Vision of the world, and all the wonder that would be ;
Saw the heavens fill with commerce, argosies of magic sails,
Pilots of the purple twilight, dropping down with costly bales ;
Heard the heavens fill with shouting, and there rain'd a ghastly dew
From the nations' airy navies grappling in the central blue. . . .

ALFRED LORD TENNYSON

THE second world war was fought as much in the sphere of applied science as with sheer weight of men and metal. Study of aerodynamics and of aircraft structure ensured an agility in manœuvre which determined the decisive nature of air warfare. As soon as flight was an established fact, the subsidiaries to flight inevitably assumed an increasing importance. Mastery of the skies, in fact, depended on aircraft equipment ; and a great measure of that mastery was made possible by radio.

Kites had been used for the support of wireless aerials during the second Boer War (1899–1902), and in 1907 the 1st Wireless Company of the Royal Engineers at Aldershot had assisted Colonel Capper in devising wireless communication between aircraft and the ground. The objects of those experiments were " to ascertain whether wireless telegraphic communication between a station on the ground and one in the air was a practical possibility, and, if so, to investigate the phenomena observed and collect information for future use."

The unhappy observers in these early experiments, using makeshift apparatus, were only able to stay aloft for a quarter of an hour at a time, owing to air-sickness caused by the motions of their captive spherical balloon. In May 1908, however, Capper made a free run in the balloon *Pegasus*, from which strong wireless signals at Aldershot

were obtained when the balloon was over Petersfield, some twenty miles away. When the balloon was near Borden Camp, Capper intercepted signals transmitted from a battleship, *King Edward VII*, lying near Portsmouth.

In January 1911 Captain H. P. T. Lefroy, R.E., made some experiments from an Army airship, recording the following passage in his log-book:

> " Petrol pipe on engine burst when half a mile from Balloon Factory. I at once informed ASX (Aldershot wireless telegraphic station) of this and told him to try and get me now that engine was not running. He at once started up and I got very loud signals and read: 'All your signals good, but . . .' and then the engine was off again, so I lost the rest. *Quite* impossible to hear signals (when engine running so close) without any special device as sound-proof helmet—could not even hear the test buzzer and barely hear the spark gap; returned to Factory and landed safely about 5.10 p.m."

Such were the beginnings of the use of radio as part of the equipment of an airman; thereafter the subject was continuously studied at Farnborough. The main value of radio in the first world war was simply that of a means of communication; during the second world war it became the universal eyes and ears of the airman.

Like many other momentous novelties hidden behind initials, the system known as V.H.F. had a profound effect upon the work of the fighters of the R.A.F. in every sphere of action. Shortly before the war, communications in the R.A.F. were made on a high-frequency wave-length. It was realised, however, that the vast expansion of the air forces in war would require Very High Frequency in order to provide enough channels for communication with the ground and in the air. This equipment was therefore installed in the Service in 1940. In conception and execution an enormous advance on previous equipment, it was from the outset superior to anything the Axis Powers were able to provide. The first sets had four channels; these were soon replaced by a light-weight model providing eight. Later the system was again improved in such a way that 300 channels could be selected merely by the operation of two rotary switches. Without going into explanatory details, it can be stated that this neat, efficient apparatus very probably revolutionised the tactics of the air by providing split-second communication at all times.

The Farnborough staff was concerned with V.H.F. from its beginnings; the story illustrates at least the virtues of self-confidence engendered during forty-odd years of continuous experiment in the uses of wireless. Research into very short-wave radio communication first appeared on the programme in 1929. At the same time, H.M. Signal School, the Naval Radio Research Establishment, began to investigate proposals which had been made by R. C. Galletti for the

generation of a parallel beam on short wireless waves. This was an associated subject; while proceeding with its own work, the Establishment provided some equipment for the Signal School. The investigations into the Galletti beam were abandoned in 1931, when certain fundamental defects had been revealed; but the work of the Establishment was continued, and use was made of the equipment constructed for the naval research. There were tests in 1931 and 1932, when new apparatus was built as the first step towards an effective ground-to-air, air-to-ground, and air-to-air Very High Frequency system. This was considered a long-term project; and as during the early nineteen-thirties the Radio Department at Farnborough was designing radio equipment for a complete refitment of the R.A.F., V.H.F. work had to be relegated to a low priority.

In 1935, however, it was revived as a development item, and for the next three years received a full measure of attention from the Departments. In 1938 the Air Ministry raised the question of the achievements of the Netherlands Air Force in the same field of inquiry. Two officers were sent to Holland to report on the Dutch equipment; they stated that it was "a sound practical working proposition" and "an advance in a practical way on everything that so far had been developed by our own Establishments."

This report naturally caused serious concern in London. It appeared that the Dutch Air Force was already, in 1938, fitting a system superior to the British system, which would not be ready for fitting until 1942. It was therefore proposed that Dutch equipment should be purchased for a full study, and that the radio industry should be called into consultation with the Establishment, being remunerated for this service without regard to the orders it might receive.

Expressions of concern did not, however, unduly perturb the staff at Farnborough. The Vice-Controller of Communications Equipment, Sir Robert Watson Watt, had no lack of faith in either the ability of the Establishment or its methods of use of the radio industry's capacity for development. He stated that the Establishment, or any competent firm, could five or six years earlier have produced an equipment similar to that of the Dutch; and that Dutch equipment could not be compared with the highly stable and selective multi-channel equipment conceived at Farnborough. The matter was therefore left as before, except that the Establishment accelerated its efforts towards development.

The introduction of V.H.F. into the Air Force had already begun when in the summer of 1939 arose another scare, this time concerning the French Air Force. Officers were again dispatched over the Channel with instructions to inspect the French equipment. They reported that the French had been using Very High Frequency in fighters for some time past, and within the last three months had "completely re-

equipped with new V.H.F. apparatus, which seemed to us extremely well designed and certainly gave excellent results." The Assistant Chief of Air Staff at Air Ministry was concerned. He wrote: "There is no doubt that the development of our W/T apparatus at the Royal Aircraft Establishment is very slow and I am sure it would pay us to emulate the French and hand over a good slice of our W/T development work to civilian firms." Sir Robert Watson Watt again added his comments, however, stating that the French "with a negligibly small air force could in 1938–39 equip with virtually hand-made sets, but would, in consequence, be unprovided with war production capacity." He went on to point out that Farnborough had always kept one eye on future large-scale output, and he made some interesting comparisons. In Germany all development after the initial design was being carried out by commercial firms. In Italy the opposite principle was adopted; radio equipment was Government-designed, and manufacturers were not permitted to depart from the prototype. Neither of these two systems had, in fact, produced results quicker than those given by the Establishment. The Germans took a minimum four and an average five years to reach production; the Italians took four years.

This story has a happy ending for Farnborough; the Establishment's methods were triumphantly vindicated. The French system was a technical failure, and the French, to quote an official comment made afterwards, "were so much impressed by the superiority of our V.H.F. equipment for fighters that they begged us to provide sets for the re-equipment of their Fighter Forces to the exclusion and rejection of the equipment so enthusiastically described."

The Germans had a V.H.F. system comparable to the British, but it did not come into wide-scale operation until about eighteen months after the British fitting. The Americans had no comparable equipment; in due course they adopted the British system, fitting it throughout their fighter force without any major modifications.

This story has been told not just to emphasise an achievement of the design department of the Establishment, but also in some measure to illustrate the intricate relationship between that department and British industry. V.H.F. could only have been conceived and designed, during a period of disarmament, in a Government establishment. The radio industry was preoccupied by its prosperous peace-time programmes, and it is doubtful whether, in 1930, technical resources, or incentive to undertake this work, were available. V.H.F. was therefore carried by the Farnborough staff to the point of practical design, and at that point industry came in with its vast resources and enthusiasm and equipped the Service. That Fighter Command had the equipment in time for the Battle of Britain was a significant factor in determining that notable victory.

TEN

THE FACE OF THE WATERS

We have fed our sea for a thousand years
And she calls us, still unfed.

RUDYARD KIPLING

ALMOST as soon as he was airborne man began to fly across water. Aviation was substantiated in the public mind more by progressive conquest of stretches of water than by more elaborate and daring feats. The flight of Blériot across the Channel seemed to shatter traditional frontiers. The crossing of the Atlantic on the night of June 14th/15th, 1919, by Sir John Alcock and Sir Arthur Whitten Brown revealed to the public the world-potential of the aeroplane in a way which a great overland flight could never have done. For many years there was controversy as to whether the new weapon of the air would overwhelm the world's navies, and if the two world wars did not finally resolve that argument, at least they left no doubt that events upon the " still unfed " seas are increasingly determined by those taking place in the air.

The relationship of flight and water has been studied at Farnborough from the earliest days, and a great deal of the Establishment's research work has ultimately concerned the sea. Farnborough lies inland, so that early experiments with water-borne aircraft had to be made on Fleet and Frensham Ponds.

By no means all experiments carried out at the Establishment provide a show for the visiting layman, but it so happens that several of the more spectacular things to be seen there relate to the sea.

There is, for example, the seaplane tank, a long gallery not unlike a section of the London Underground, if you can imagine three or four feet of water let in rather like a swimming-bath between the lines. To further the " Underground " illusion, a trolley runs on wide-gauge rails, taking a party of observers and the necessary testing equipment at a speed of about 30 m.p.h. a few feet above the surface of the water. The subjects for test in this tank, which cannot fail to please children of all ages, are the models of the hulls of flying-boats. Their behaviour in water is tested in very much the same way as is the behaviour of aircraft models in the wind tunnels.

Again, in a far corner of the many acres of buildings occupied by the Establishment there are several open tanks which serve an ordinary industrial purpose and would be unremarkable but for the catapulting gear erected at one end of them. From this gear, scale models of air-

craft, much more completely fitted than those used in the wind tunnels, are ejected into the air. After a few yards of flight, they come down on the surface of the water, simulating the process of "ditching." Careful investigations of their ditching behaviour are made; from time to time parties of visiting pilots have had uncomfortable moments observing how the aircraft they have habitually flown on operations meet the water.

The practical value of this small experimental corner was demonstrated in the early stages of the war, following the loss of nearly fifty Hudson aircraft at sea without trace during the course of a year. A model was made representing correctly the weight and size, and also the breaking strength of the vulnerable parts such as bomb-doors, flaps, and bomb-aimer's window, of the full-scale Hudson. This model was catapulted on to the water in the way in which it would normally be ditched, and its subsequent behaviour was photographed. The photographs showed that failure of the bomb-doors and the bomb-aimer's window, together with the drag of the flaps, produced a fatal tendency to dive. The strengthening of the doors and window, and a study of the best handling technique for ditching, undoubtedly contributed to the subsequent increase in the numbers of crew rescued from Hudsons. The case of the Flying Fortress was not without interest. Model tests showed these aircraft to be good ditchers, whereas in operations there was heavy loss of crews. Attention, therefore, was concentrated on the importance of ditching drill among the crews, with the result that 118 out of 121 Fortress crews were rescued in one day's operations.

If the visitor to Farnborough is lucky, he may see trials of naval aircraft taking place on a runway given over to this work. At one end is the catapulting base from which aircraft are launched, and near the middle is the deck arresting equipment where aircraft can be brought to rest from flying speed in a distance of 50 yards. There are several of these rigs which simulate conditions at sea, and all manner of experiments are carried out on them, for the Farnborough Establishment has collaborated with naval airmen since the earliest days.

The principle of carrier-borne aircraft was established in December 1911, when Lieutenant C. R. Samson, R.N., succeeded in flying a biplane from a special deck built on the forecastle of H.M.S. *Africa*, then lying at anchor in Sheerness Harbour. Nowadays a vital mechanism in the aircraft-carriers which serve the lineal descendants of Samson's machine is the catapult which assists aircraft to take off from the deck under conditions which would prevent normal flying off. It is often called the carrier's "big gun," by virtue of its ability to shoot off from the forward end of the flight deck its striking force of bombers or fighters.

The carrier, with its flat flight deck, offers a vulnerable target to a determined enemy, and must therefore be in a position to defend itself

with its own aircraft. By means of a catapult the carrier can put up a squadron of fighters in a matter of minutes, without taking into consideration the direction or velocity of the wind, which had to be watched so carefully when aircraft flew off under their own power. One of the aircraft-carrier's difficulties is to be able to operate its machines while moving and remain at battle station with the Fleet. Assisted take-off provides the means of accomplishing this ; it also enables the ship's squadrons to be used while the carrier is at anchor in almost any harbour.

Catapults, originated by the R.A.E. in 1922, had been in use for many years in *Ark Royal*, *Courageous*, and *Glorious*, but the mechanism was of a type which made loading and launching a lengthy process. The superstructure, or trolley, which supported the aircraft was heavy and cumbersome. Aircraft in former days, being comparatively slow and light in weight, could more often than not be more easily flown off without this rather clumsy assistance. The modern technique of waging war at sea with aircraft-carriers had not, moreover, been developed, and it was the advent of the new, more modern fleet carriers, together with the much heavier and higher-performance aircraft, that necessitated a new approach to the subject.

This work was begun in 1937 at Farnborough. The design for the new *Illustrious* class carriers was already in hand, and the Admiralty required a catapult capable of launching aircraft from the carrier at the rate of one every forty seconds. The Establishment tried out various schemes from its runway on Jersey Brow, in addition to trials on carriers already in service. A prototype equipment was started in March 1939. It was fitted to H.M.S. *Illustrious* in May 1940, and taken immediately into service. The new gear required only five ratings to load the aircraft, and the new trolley was designed in such a way that it could be adjusted to suit all Fleet Air Arm aircraft in service at the time.

In 1942 the policy of the Admiralty in view of the U-boat menace was to build small carriers for escort aircraft duties. To these carriers it was decided to fit a simplified form of accelerator with twin tracks. A prototype was designed and built at Farnborough, and rapid launching was demonstrated in October 1942. As a result of these trials, all fleet carriers were fitted with the new type of trolley. It was first used operationally in the Battle of Matapan, and thenceforward became an integral part of the naval service.

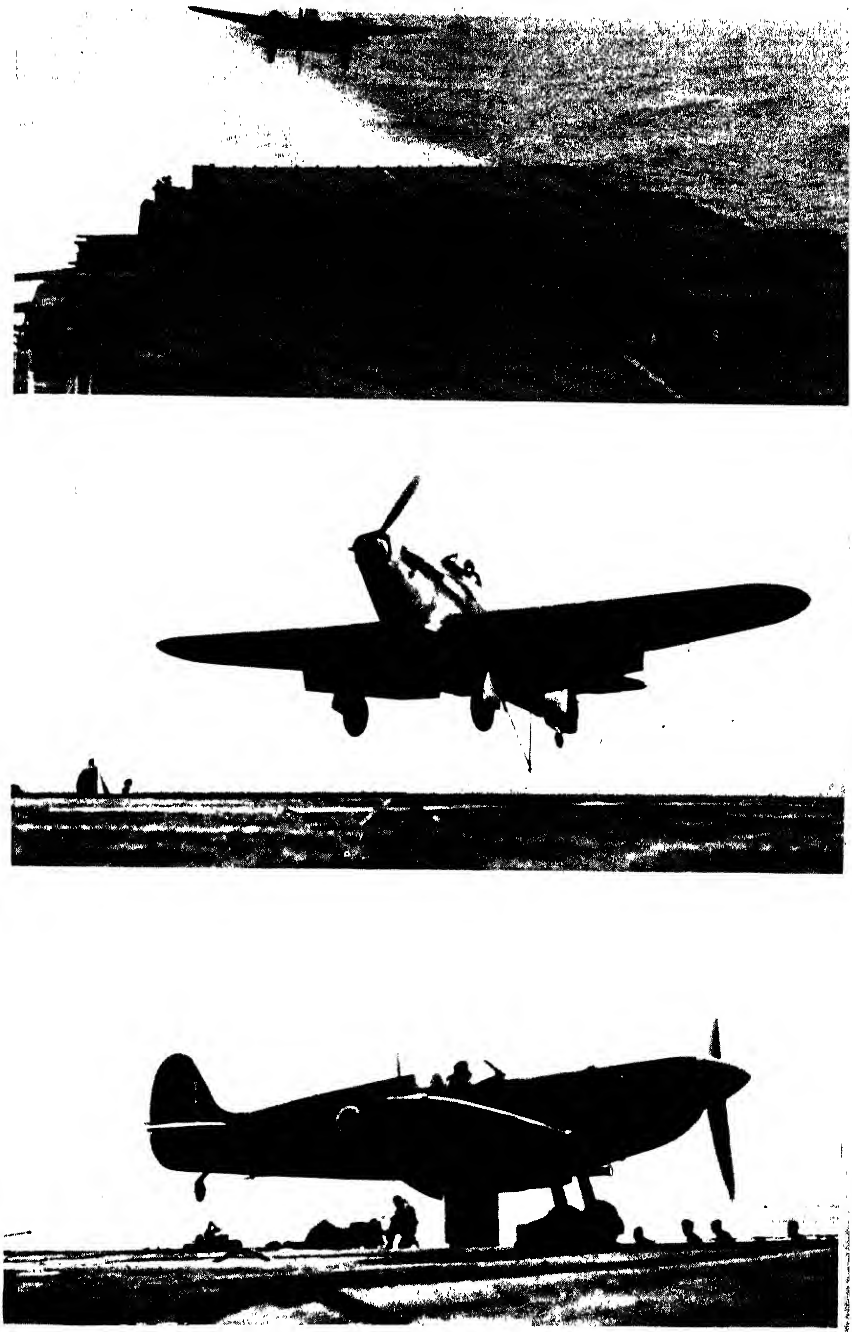
Perhaps the longest and the most tenacious struggle of the second world war was the Battle of the Atlantic. Farnborough took a hand in its earliest stages, when the Germans began to use long-range aircraft in attacking our shipping, and to assist U-boats in that part of the mid-Atlantic then outside the range of our shore-based air patrols. As an emergency measure to meet a dangerous situation,

suggestions were made that fighter aircraft should be mounted upon merchant ships, though it was realised that unless the aircraft could reach land after being launched, the pilot would have to bale out and the aircraft would be lost. Those were days which called for quick action, and the Farnborough Establishment undertook to investigate and develop in three weeks a method of launching with equipment which could be speedily installed in existing shipping.

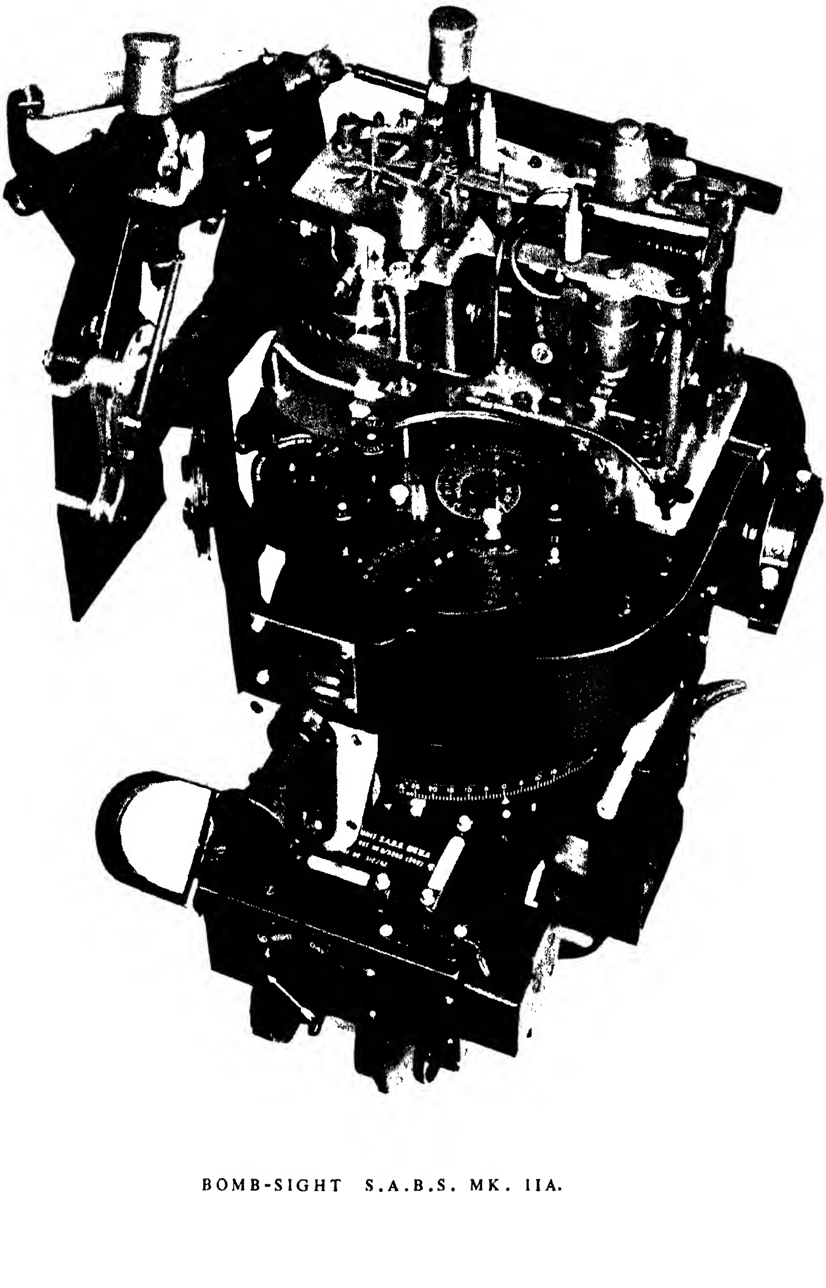
It was decided that the aircraft would be supported at the normal catapulting spools in a simple rigid trolley which would itself be guided in a channel track. A suitable track was erected on the airfield at Farnborough, built from a couple of obsolete catapult structures bolted together and supported on sleepers. The trolley itself was made chiefly from angle iron salvaged from the debris of one of the few bombs which fell on the Establishment. A simple retarding gear was developed. While the trolley and track were being completed, a series of full-scale dead launches were carried out, use being made of an old truck ballasted up to aircraft weight and running in a length of rail. Propulsion was by rocket, and it was soon found that the total number of rockets required could not be fired in one group. By means of a number of rockets fired in several groups, however, satisfactory launching was obtained of aircraft up to 10,000 lb. in weight with a stroke of 70 feet in varying winds and at varying temperatures. Twenty-five days after the job was taken on, the chief test pilot of the Establishment, Wing Commander (now Group Captain) H. J. Wilson, demonstrated the new weapon before an audience of Admiralty and Air Force officers. When the designs were completed, they were handed over to the Admiralty, who undertook the placing of contracts for the production of tracks and trolleys in quantity. The first three ships fitted out were converted banana boats, manned by the Royal Navy ; first of the three was H.M.S. *Ariguani*, which was ready in April 1941. Between April and October 1941, thirty-eight vessels were equipped with the catapulting device.

Rather outside its original terms of reference, but of some historical interest nevertheless, was the fact that Farnborough, which possessed the only shore-based installation available, undertook a training programme for the pilots and ground crews who were to use this new device. In from three to four months some sixty Naval and R.A.F. pilots with 140 ground crew passed through a training course in the Establishment.

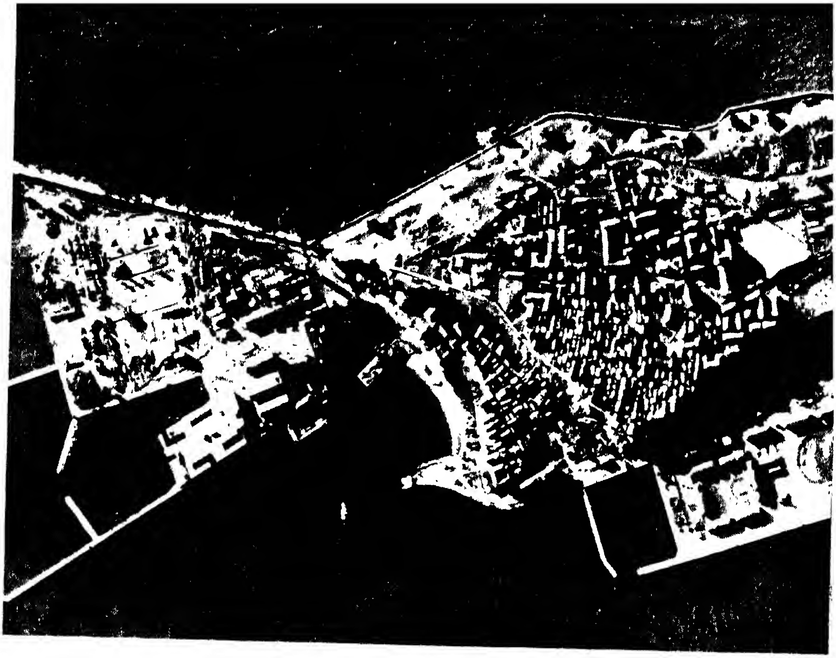
The increase in speed and weight of land-based aircraft has naturally necessitated wider and longer runways, but no such provision has been possible for carrier-operated aircraft, whose landings must be made on the after-part of a flight deck in a space only 100 yards long and up to 30 yards wide, upon a surface which is subject to the normal rolling and pitching of a ship at sea.



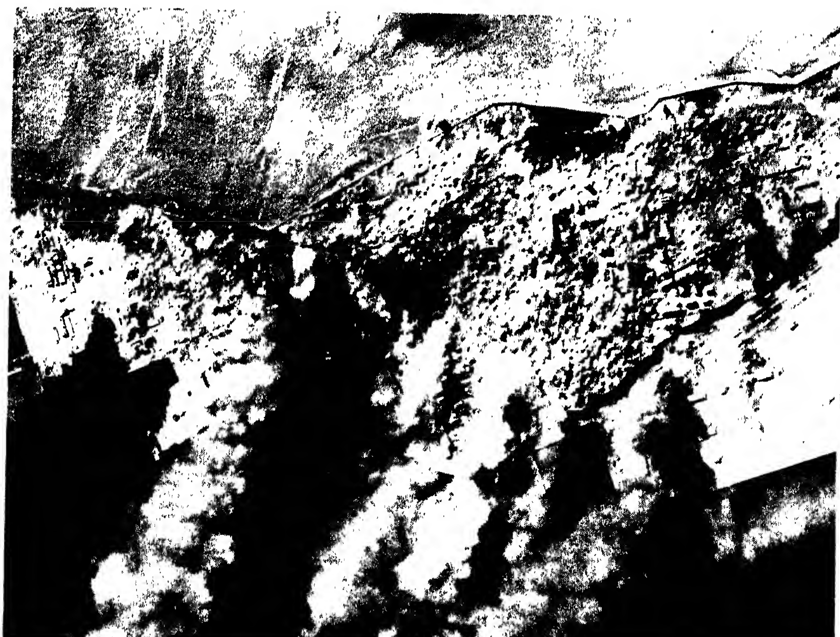
FIGHTER DECK-LANDINGS ON CARRIER. Many years' work at Farnborough resulted in successful development of the arrester gear necessary to ensure safe landing on aircraft-carriers.



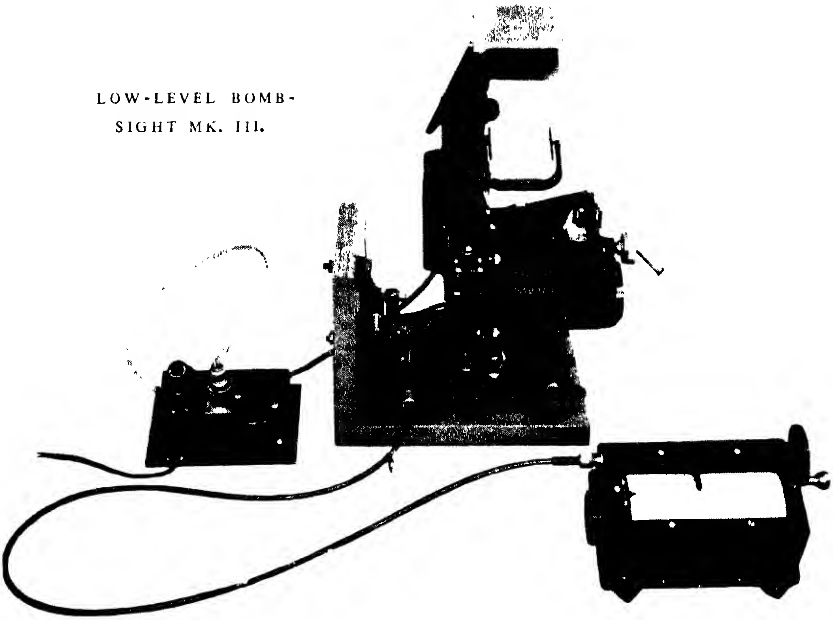
BOMB-SIGHT S.A.B.S. MK. IIA.



HELIGOLAND BEFORE AND AFTER BOMBING, 1945. Thirty years of continuous work have gone to the evolution of high-altitude bomb-sights. These photographs show the accuracy obtained by the use of such bomb-sights in actual operation.

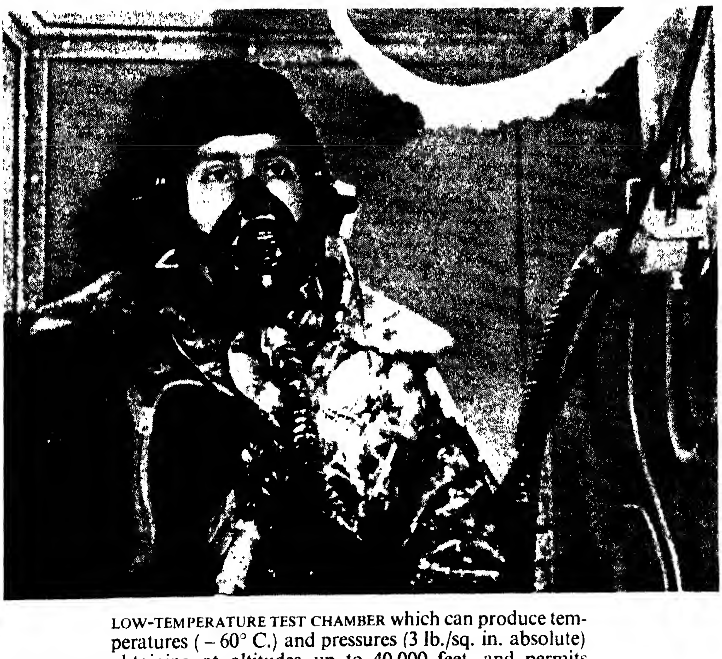


LOW-LEVEL BOMB-SIGHT MK. III.



LOW-LEVEL ATTACK ON U BOAT. The low-level bomb-sight was produced by the Establishment for accurate attack on submarines and was responsible for a considerable increase in U-boat losses. An actual example of such a low-level attack and the accuracy of result obtained are seen in the accompanying illustration.

HIGH-ALTITUDE RECORD AEROPLANE AT FARNBOROUGH, 1937. An example of peace-time co-operation by the Establishment with the aircraft industry is shown in the successful attempt on the world's altitude record (53,937 ft.) on June 30th, 1937. The pilot was F.-Lt. M. J. Adam, a test pilot of the Establishment who was killed on duty soon afterwards. In this project the Establishment did considerable work on the aircraft, engine, and pilot's pressurised suit.

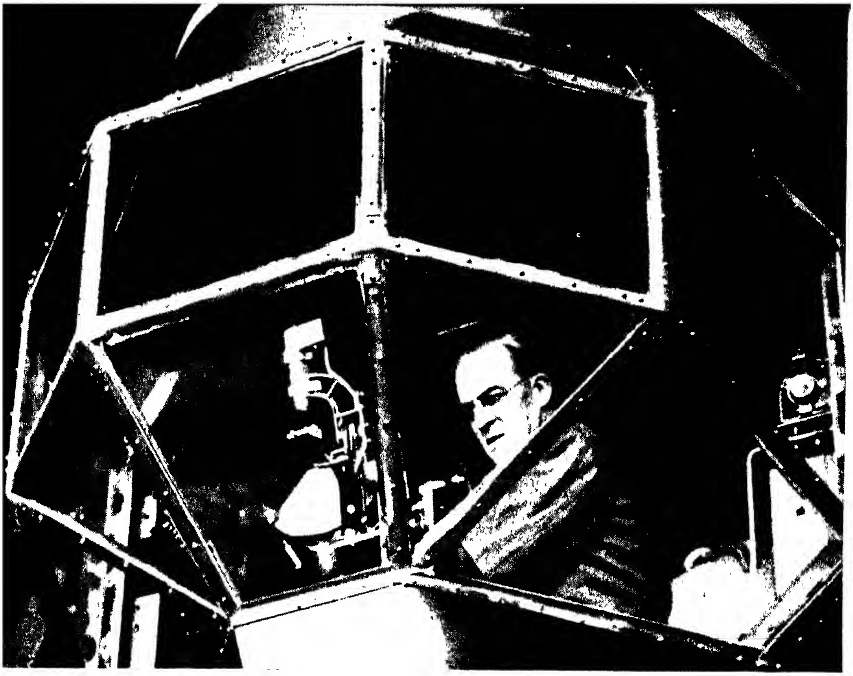


LOW-TEMPERATURE TEST CHAMBER which can produce temperatures (– 60° C.) and pressures (3 lb./sq. in. absolute) obtaining at altitudes up to 40,000 feet, and permits simulation of actual flying conditions in the laboratory.

H.M. QUEEN MARY at Farnborough, 1910. On the left, with field-glasses, is FIELD-MARSHAL EARL (then VISCOUNT) KITCHENER.

H.M. KING GEORGE V at Farnborough, 1917, with SIR HENRY FOWLER, then Superintendent of the Establishment.

H.M. KING GEORGE VI at Farnborough, 1940, with AIR VICE-MARSHAL A. L. TEDDER, COL. J. J. LLEWELLIN, MR. A. H. HALL (Chief Superintendent, R.A.E.), MR. ANDREW SWAN (Superintendent, Technical Development), DR. B. H. C. MATHEWS (Head of A.M. Physiological Laboratory), and MR. W. G. A. PERRING (then Superintendent of Scientific Research, now Director, R.A.E.). Since the early days of flying at Farnborough, the Royal Family have been constant visitors to the Establishment.



THE RIGHT HONOURABLE SIR STAFFORD CRIPPS, then Secretary of State for Air, at Farnborough, 1943.

AMERICAN VISITORS AT FARNBOROUGH, 1943. During the war constant liaison was maintained with our Allies. Among the many visitors was GENERAL CARROLL, here shown with MR. W. S. FARREN, Director of the Establishment, and MR. H. L. STEVENS, Deputy Director, Aircraft and Flight Experiments.

MARSHAL OF THE ROYAL AIR FORCE LORD TEDDER and MARSHAL OF THE ROYAL AIR FORCE VISCOUNT PORTAL with MR. W. S. FARREN, the Director of the Establishment, at Farnborough, 1945.

At Farnborough during the British Aircraft Exhibition in 1945: on the left, LORD WINSTER, Minister of Civil Aviation; behind him, MR. H. L. STEVENS, Deputy Director of the Establishment. On the right, MARSHAL OF THE ROYAL AIR FORCE LORD TEDDER and (in front of LORD TEDDER) MARSHAL OF THE ROYAL AIR FORCE VISCOUNT TRENCHARD.

In the very early days of carrier operation, the landing speeds of aircraft were so low that by steering the ship into wind, and so creating a high wind-speed over the deck, such landings could be achieved without additional help. As landing speeds increased, however, it became necessary to devise other means for stopping the aircraft within the limited space available, and the Establishment tackled this problem. The principle adopted makes use of a hinged arm which can trail from the after-part of the fuselage, and which terminates in a hook. The arm is retracted during flight in the same way as an undercarriage, and is lowered as the aircraft approaches to land. On touch-down, the hook engages with one of a number of wire ropes stretched a few inches above the deck. The ends of these ropes are reeved about a ram installed below, and as the aircraft tows out the ropes the ram is closed against controlled hydraulic resistance. Innumerable experiments have been made both at Farnborough and at sea to improve the performance of these gears.

The " proofing " of each new type of naval aircraft is carried out as a routine matter by catapulting and arresting under abnormally severe conditions, special recording instruments and high-speed cine-cameras being used to study the behaviour of the aircraft.

On the defensive side of sea warfare, Farnborough was presented with a very urgent problem in the second world war, when the Royal Navy recovered the first of the magnetic mines from the shallow water of the Thames Estuary just off Shoeburyness. The Establishment, in close collaboration with the Admiralty Research Laboratories, set out to determine the characteristics of the magnetic mine unit and its behaviour when subjected to a moving magnetic field, in order that aircraft might be equipped to produce such magnetic fields and carry out sweeping duties. It was the practice of the Germans to sow the mines in sheltered coastal waters ; as they were laid on the bed of the sea, normal methods of sweeping could not be used. The use of an aircraft carrying some sort of magnet was suggested as a means of destroying the mines. Mathematical investigation showed that the most efficient form of coil would have an air core and a diameter as large as possible. The equipment—designed in close collaboration with Vickers-Armstrong, the English Electric Co., the Engine Section of the de Havilland Aircraft Co., and a number of other firms—was installed in a Wellington. It comprised a 200 b.h.p. D.H. Gipsy Queen aero engine, driving an English Electric generator, which, in turn, supplied power to a 48-foot diameter coil formed from aluminium strip. The coil was enclosed in a stream-lined casing, arranged with special ventilation for cooling and supported at four points, two on the fuselage and two on the wings. It was realised that if the aircraft was too close to the mine there might be damage from the explosion. In order to lay down conditions under which it would be safe to sweep, it was therefore

necessary to determine the position at which the mine would explode relative to the aircraft, and the nature of the disturbance of the surface of the water produced by an under-water explosion. A series of scale model experiments was conducted in collaboration with the Admiralty Research Laboratories. An electromagnet simulating the effect of the coil of the aircraft was mounted on an overhead runway and made to traverse a mine-firing unit at speeds corresponding to the passage of the aircraft over the mine. Mathematical relationships were developed by means of which it was possible to deduce the effect of the actual coil carried on the aircraft, and full-scale tests ultimately confirmed the accuracy of these predictions. Wellingtons, singly, and later in formation, went mine-sweeping until such time as the Germans altered the characteristics of their mines. In addition to sweeping in British waters, these aircraft gave great service in the Middle East, keeping the Suez Canal free from mines.

ELEVEN

SCIENCE ITS INSTRUMENT

All that science deemed absurd
Has made of science its instrument;
The physicist and engineer
Renew our superstitious fear . . .

RICHARD CHURCH

NEITHER naval nor military aviation would have been the forces they are to-day had it not been for much basic research into every detail of the airman's being and the machine's substance. One of the immediate concerns of a civilisation which embodies man's ability to fly is the degree of his safety in flight. This safety is not merely a commercial selling point, but a quality necessary for day-to-day efficiency of the community in peace and in war. Let us then consider, in the closing pages of this narrative, a few aspects of the progress of flying more human and personal, though not less important, than some of the fundamental issues already mentioned.

A notorious enemy of man in the air, as upon the earth, is fire. From the earliest days at Farnborough there were casualties from fire. One of the most outstanding members of the Establishment staff, that daring pilot and brilliant scientist E. T. Busk, was killed in November 1914 when his B.E.2c machine caught fire at 800 feet. The dangers of fire became really apparent during the first world war, and were the subject of many experiments. One of the most courageous of these was

carried out by Major G. H. Norman in 1921. He was very much impressed by the fire-prevention apparatus sent for test by a French firm, which he had tried out on the ground with great success. He had such confidence in the apparatus that he determined to try it out in the air. He therefore flew off from Farnborough in an S.E.5 (in those days, of course, not being equipped with a parachute). After several attempts, he succeeded in deliberately setting his aircraft on fire. The apparatus worked ; but unfortunately as he came in to land, half blinded by smoke, he ran the aircraft into an excavation and it turned over. He appeared to be uninjured, but collapsed and died some time afterwards.

During the recent war, over a hundred full-scale fire tests were made at Farnborough on typical British and American liquid- and air-cooled engines installed in aircraft. Some of these fires, in conditions simulating large leakages of fuel, oil and boosted fuel-air mixture, were very severe. The fires were all successfully extinguished with an apparatus now fitted to all multi-engine aircraft ; it is claimed that,as a result of research in this subject, 90 per cent. of fires which occur in the air can be extinguished.

The Establishment has influenced the design of the induction and exhaust systems in engine power plants, and has paid special attention to keeping petrol and oil pipes as far as possible away from places where fire may occur. As fire extinction depends so largely on the speed with which the fire is tackled, rapid fire detector switches connected to warning lights on the pilot's instrument panel are now fitted in aircraft.

To fight an engine fire, action is taken to stop the engine as quickly as possible, supplemented by the injection of methyl bromide into the induction system. After the engine has stopped, methyl bromide from a separate bottle is sprayed through perforated tubes into the nacelle so that the engine is literally enclosed in an envelope of inert gas in which combustion is impossible.

Work on safety precautions for the repair of fuel tanks in damaged aircraft during the Battle of Britain led to a thorough investigation of the fire and explosion risks associated with fuel systems. Apart from the danger of fuel from a tank wound being ignited in the wing, it was found that there was considerable risk of an explosive mixture of fuel-vapour and air forming inside the tank. Laboratory experiments indicated that such danger arose from the reduction of volatility of the fuel at the low temperatures encountered in flight, and were further increased by tank breathing. Fire trials were made on fuel tanks at low temperatures to confirm laboratory work and to assess damage. An explosion caused by a single round of ·303 incendiary ammunition was found to be serious and some losses of aircraft from this cause seemed to be inevitable, and were in fact confirmed by the Operational Research Section of the Air Ministry. Fires from this source have

been prevented by the introduction of an inert gas in the space above the fuel. Incendiary bullets penetrating a tank under such conditions cannot cause an explosion because there is no explosive mixture to permit it. The introduction of self-sealing tanks also considerably lessened fire risks.

The oxygen cylinders so essential to crews at high altitudes were also items which needed special strengthening against shell fire. The whole subject of oxygen is vital in all approaches to modern aeronautics.

Machines can be built which will operate successfully under a very wide range of conditions, whereas man can only operate efficiently under a set of conditions comparatively rigid. He cannot, for example, suffer air temperature changes without severe discomfort ; moreover, he is affected by changes of air pressure, by the quantity of oxygen inhaled at each breath, and by the rate of change in direction and movement. All these frontiers of human endurance must be limiting factors in the performance of an aircraft unless the human being himself be modified to meet them. Fortunately the Physiological Laboratory of the R.A.F. was a guest at Farnborough throughout the last war, and a team of R.A.F. medical experts has been able to collaborate with other scientists in the very many problems of the human body which dominate the progress of aviation. An Establishment war report describes these experts in these words : " They have been, so to speak, medical consultants who can place man in the most favourable conditions for flying. They are equipped with elaborate plant for simulating flying conditions and are utterly reckless in using themselves as test subjects."

The very valuable results obtained from this collaboration present an interesting contrast to the results gained by unethical approaches to similar studies made in Nazi Germany. As in Britain machines are tested to destruction, so in the concentration camps human beings were tested to destruction. Examination at Farnborough after the war of the results of Nazi experiments in human life relating to high-altitude flying, and to resistance to cold during immersion, have revealed very little which was not already known to us by means of the voluntary tests undertaken by doctors and scientists.

Until high speeds and high altitudes were reached, man was able to ride the air without more than simple physical equipment. During 1935 the Establishment was working out pressure suits to be used for the high-altitude record attempts of 1937–8. In the course of this work the first tight-fitting oxygen mask was used in an aircraft. From this beginning, an equipment was devised in time for the second world war, which gave air crew a constant flow of oxygen. The flow, in fact, was constant whether the man was breathing in or out, and a great improvement was made when an " economiser " was fitted regulating the supply to the rhythm of a man's breathing. During the course of

the war, portable oxygen sets were devised with which a man could make a parachute jump from 40,000 feet, a quick-release coupling of the main supply having been perfected to improve the safety of the baling-out procedure. These sets gave a ten-minute supply.

A great enemy of air crew is extreme cold ; heating systems had to be worked out not only for airmen's clothing but for the aircraft and instruments. Experiments with clothing showed the possibility of many refinements, such as the redistribution of heating elements to provide an adequate temperature over the whole body, generally by increasing heat at the extremities.

Practical experiments at Farnborough produced the first pressurised cabins for the standard Spitfire. As the main authority of such installations, the Establishment was selected for the task of producing a special pressurised sleeping compartment for Mr. Winston Churchill's personal use as Prime Minister during his war journeys by air. It was designed, assembled, and tested at very short notice, and was capable of maintaining low-level conditions up to the maximum altitude of the aircraft.

The British version of that good and trusty friend of all pilots, "George", the automatic pilot, was born at Farnborough most obscurely in the early 1920's. A great deal of basic research—independent of the work already being done in America—went into this important equipment in those days, but publication of the results caused little interest in either industrial or Service circles. "George", in fact, was quite forgotten for some years, until the Americans began to make known their work on a similar project. They devised a pilot efficient in terms of its function, but of a size and weight which made it impracticable. Nevertheless, interest in the American model was aroused in London, and negotiations for its manufacture in this country had actually been initiated when the early work at Farnborough was recalled. "George" was immediately restored to the Establishment's programme, and by the beginning of the war there was a universal installation for British aircraft requiring his presence.

On the airfield at Farnborough is a control tower which is a veritable showpiece. Under the charge of Mr. Gill Harris, who has been in aviation ever since he ran errands as a boy for the Hon. C. S. Rolls, this control tower is a proving-ground for new devices and navigational aids which are forming a new basis of civilian aviation in this country and throughout the world. It is fitting that such a laboratory of wisdom and safety should rise up by the side of Cody's Tree. The juxtaposition emphasises the continuity of purposeful progress of which each has been a part.

TWELVE

EPILOGUE

ON a sunny April morning in 1945 one of the most brilliant of the young scientists who had worked at Farnborough throughout the war entered a house in Bad Eilsen, Germany, more or less on the heels of the British occupying troops. The formidable structure of German scientific warfare was crumbling, and the men from Farnborough who had pitted themselves against its work were at last moving into Germany. In the house at Bad Eilsen, a young German scientist sat calmly, with studied scientific detachment, carrying on with his task of writing a text-book on aerodynamics. The British scientist looked round the sunny room, so peaceful in the midst of the turmoil of collapsing scientific hopes. He noticed one of his own scientific publications among the text-books from which the German was working. He sat down. They began to talk shop.

Such was the ending of a period of intensive endeavour directed against an enemy. W. G. A. Perring, the present Director of the Royal Aircraft Establishment, soon afterwards made a quick tour by air of all his former rivals' units in Germany and Austria. It was a satisfactory ending to an immense effort, of which Farnborough had been the focus ; but if these men of invention felt exultation there was little sign of it. Systematically they began to play their part in taking over and dismantling the scientific machinery which had constituted such a menace to the world. They probably knew more about it than most people in this country, for they had long recognised that the side with the more efficient intelligence service would always have the advantage. Throughout the war they had realised the very important part of technical development contained in the provision of effective counter-measures to new enemy equipment.

The first few enemy aircraft shot down over this country were naturally objects of the greatest interest, and a team of experts from Farnborough was detailed for the sole task of examining these wrecks in detail. The supply of them soon became more plentiful, and it was possible in some instances to repair different types and put them through flight tests to determine their capabilities. After the Battle of Britain and the bombing raids, Farnborough in fact possessed a not insignificant Luftwaffe, and it was a common event to see mimic dog-fights between British and German aircraft over the Farnborough Common. A great responsibility in connection with captured aircraft rested on the shoulders of such distinguished test pilots as Group

Captain H. J. Wilson, of the Experimental Flying Department former holder of the world speed record. This pilot, for example, carried out the flight performance tests of the Ju. 88, the Me. 109 and 110, as well as on the first Focke-Wulf 190 to be captured, the engine of which "gave considerable cause for anxiety." Needless to say, the tests were of the utmost importance, the aircraft being the only ones of the type in our possession intact at that time: and it was a matter of urgency to discover their performance.

An intensive study was also undertaken, at the request of the Ministry of Economic Warfare, of the construction methods of the Luftwaffe, in order to seek out any weaknesses in the economic and production centres in Germany. Some items were of particular interest, for instance, because the highly specialised mode of manufacture meant that their production was very localised and afforded a profitable target for attack.

The German from Bad Eilsen now occupies a work-bench at Farnborough, where, as already noted, several of the more talented of his countrymen have found a place beside the British scientists. There is no longer an enemy to stimulate the activities of this laboratory of the air. Inevitably economies have set in, but the lessons of the past have been learnt, and Farnborough, though it no longer continues to employ a huge war-time staff, is assured of its continuity in the life of the nation. Aeronautics in the future will demand even more powerful tunnels and equipment than Farnborough possesses to-day, and a number of workers within the Establishment are busy on the design of the new tools, and are looking forward to occupying a more spacious home in the forthcoming National Aeronautical Establishment to be located in Bedfordshire. Wherever the work goes on now, the valuable threads of thought will remain. They are interwoven in the philosophies of the air. They are part of the structure of our lives, since for good or ill we live in an air age.

MINISTRY OF SUPPLY